DOC.20040908.0007

QA: QA

ANL-MGR-MD-000003 REV 03

September 2004

Disruptive Event Biosphere Dose Conversion Factor Analysis

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DE-AC28-01RW12101

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QA: QA

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September 2004

OCRWM	Scientific Analysis Signature Page/ Change History	Page iii 1. Total Pages: 154

2. Scientific Analysis Title			
Disruptive Event Biosphere Dose Conversion Factor Analysis			
3. DI (including Revision Number) ANL-MGR-MD-000003 REV 03			
4. Total Appendices 5		5. Number of Pages in Each Appendix A – 8 pages, B – 8 pages, C – 26 pages, D – 4 pages, E – 4 pages	
	Printed Name	Signature	Date
6. Originator	Maryla A. Wasiolek	SIGNATURE ON FILE	9/7/2004
7. Checker	Ernesto Faillace	SIGNATURE ON FILE	9/7/2004
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10. Responsible Manager	Ming Zhu	SIGNATURE ON FILE	9/8/04
11. Remarks			

Change History

12. Revision No.	13. Description of Change
REV 00	Initial issue
REV 01	Incorporate revised exposure scenarios, re-developed input parameters, add pathway and limited sensitivity analyses, append list of radionucldies, remove bounding case, add validation of the biosphere model.
REV 02	Complete revision following development of the new biosphere model, ERMYN.
REV 03	Revision to incorporate Regulatory Integration Team review comments and to address Condition Report No. 2222 (implementation of Action No. 2222-001) concerning Latin Hypercube sampling scheme in GoldSim. The analysis is a complete revision; no change bars were used.

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ACRONYMS

AC	acceptance criterion
BDCF	biosphere dose conversion factor
DCF	dose conversion factor
DOE	U.S. Department of Energy
ERMYN	Environmental Radiation Model for Yucca Mountain, Nevada
FEP	feature, event, and process
LA	license application
NRC	U.S. Nuclear Regulatory Commission
QA	quality assurance
RMEI	reasonably maximally exposed individual
TSP	total suspended particulate
TSPA	total system performance assessment

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1. PURPOSE

This analysis report is one of the technical reports containing documentation of the Environmental Radiation Model for Yucca Mountain, Nevada (ERMYN), a biosphere model supporting the total system performance assessment (TSPA) for the license application (LA) for the Yucca Mountain repository. This analysis report describes the development of biosphere dose conversion factors (BDCFs) for the volcanic ash exposure scenario, and the development of dose factors for calculating inhalation dose during volcanic eruption.

A graphical representation of the documentation hierarchy for the ERMYN is presented in Figure 1-1. This figure shows the interrelationships among the products (i.e., analysis and model reports) developed for biosphere modeling and provides an understanding of how this analysis report contributes to biosphere modeling. This report is one of two reports that develop biosphere BDCFs, which are input parameters for the TSPA model. The *Biosphere Model Report* (BSC 2004 [DIRS 169460]) describes in detail the ERMYN conceptual model and mathematical model. The input parameter reports, shown to the right of the Biosphere Model Report in Figure 1-1, contain detailed descriptions of the model input parameters, their development and the relationship between the parameters and specific features, events and processes (FEPs). This report describes biosphere model calculations and their output, the BDCFs, for the volcanic ash exposure scenario. This analysis receives direct input from the outputs of the *Biosphere Model Report* (BSC 2004 [DIRS 169460]) and from the five analyses that develop parameter values for the biosphere model (BSC 2004 [DIRS 169671]; BSC 2004 [DIRS 169672]; BSC 2004 [DIRS 169673]; BSC 2004 [DIRS 169458]; and BSC 2004 [DIRS 169459]). The results of this report are further analyzed in the *Biosphere Dose Conversion Factor Importance and Sensitivity Analysis* (Figure 1-1).

The objective of this analysis was to develop the BDCFs for the volcanic ash exposure scenario and the dose factors for calculating inhalation doses during volcanic eruption (eruption phase of the volcanic event). For the volcanic ash exposure scenario, the mode of radionuclide release into the biosphere is a volcanic eruption through the repository with the resulting entrainment of contaminated waste in the tephra and the subsequent atmospheric transport and dispersion of contaminated material in the biosphere. The biosphere process model for this scenario uses the surface deposition of contaminated ash as the source of radionuclides in the biosphere. The initial atmospheric transport and dispersion of the ash as well as its subsequent redistribution by fluvial and aeolian processes are not addressed within the biosphere model. These processes influence the value of the source term that is calculated elsewhere and then combined with the BDCFs in the TSPA model to calculate expected dose to the receptor. Another objective of this analysis was to re-qualify the output of the previous revision (BSC 2003 [DIRS 163958]).

This analysis is a revision of the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958]). The analysis was performed in accordance with the *Technical Work Plan for Biosphere Modeling and Expert Support* (TWP) (BSC 2004 [DIRS 169573]).

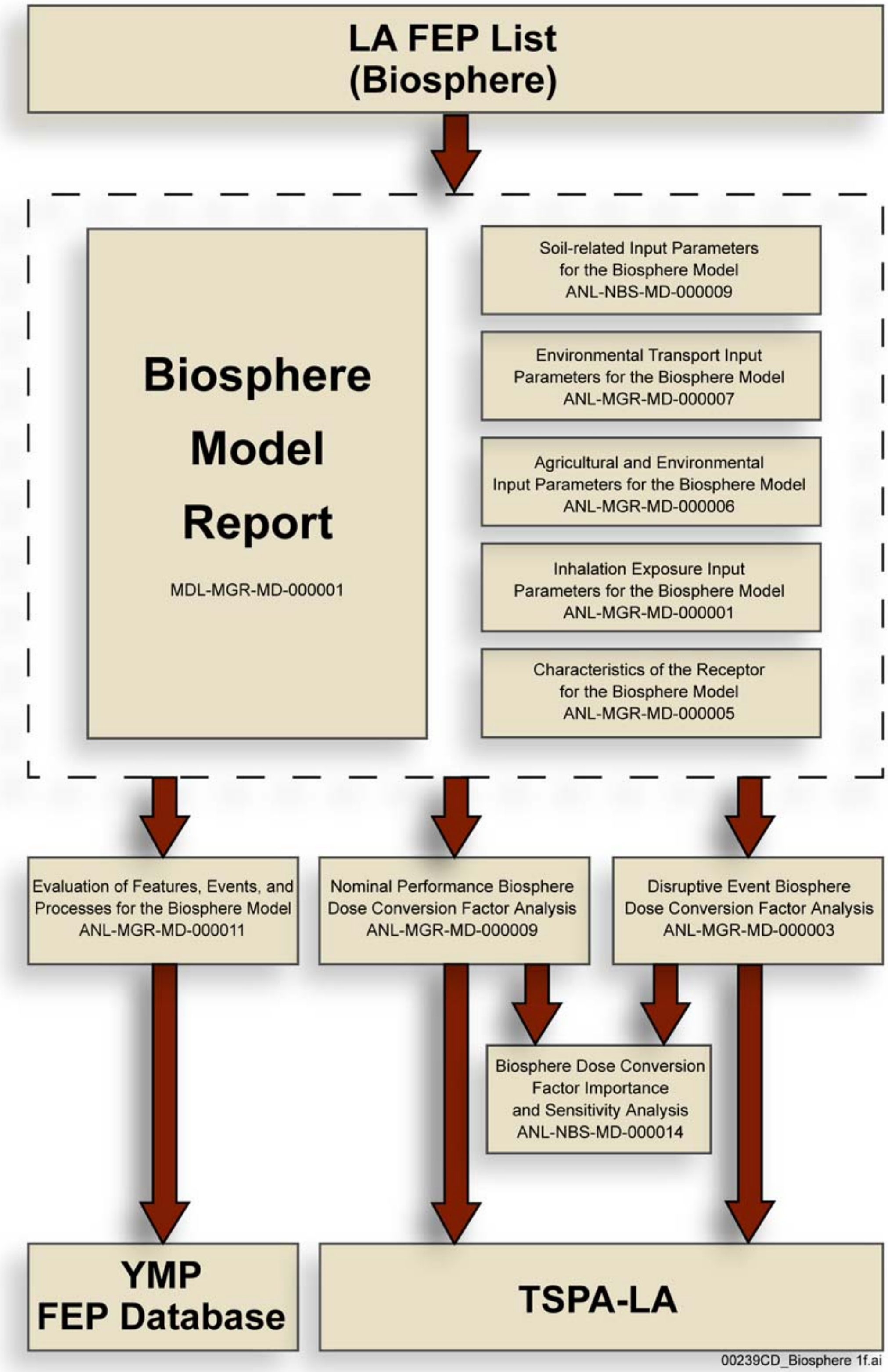

Figure 1-1. Biosphere Model Documentation

The biosphere model considers FEPs applicable to the Yucca Mountain biosphere (DTN: MO0407SEPFEPLA.000 [DIRS 170760]). Consideration of the *LA FEP List* (DTN: MO0407SEPFEPLA.000 [DIRS 170760]) constitutes a deviation from the technical work plan (BSC 2004 [DIRS 169573]), which referred to an earlier revision of the FEPs list (DTN: MO0307SEPFEPS4.000 [DIRS 164527]). Table 1-1 lists FEPs that are included in the biosphere model for the volcanic ash exposure scenario (BSC 2004 [DIRS 169460], Tables 6.2-1 and 6.3-6). Relationships among the biosphere-related FEPs, the biosphere conceptual model, and the exposure scenarios are examined in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.3); the disposition of the included FEPs within the mathematical model, and their explicit relationship to the model equations and input parameters is presented in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Table 6.7-1).

The BDCFs developed as output of this report, and used as direct inputs to the TSPA, are the results of the biosphere model and are based on the inputs from the supporting parameter reports. The BDCFs, therefore, implicitly include the FEPs that are related to the model and to the model inputs taken from the supporting parameter reports. Consequently, explicit mapping of individual FEPs listed in Table 1-1 to specific sections of this report and BDCFs is not possible. All FEPs considered in the biosphere model and its input parameters are collectively included in the BDCFs.

In addition to producing the BDCFs for the volcanic ash exposure scenario, this analysis develops the values of inhalation dose factors for calculation of inhalation doses during a volcanic eruption. Inhalation dose factors are multipliers, similar to BDCFs, and are used in the TSPA to evaluate inhalation dose accrued during a volcanic eruption. The BDCFs do not include contributions from inhalation of the falling contaminated ash. They are developed for the conditions following ash deposition and are calculated using the ERMYN model in terms of annual doses. The ERMYN is not used to calculate inhalation dose factors. The FEPs that are related to inhalation dose factors are listed in Table 1-2. The disposition of these FEPs in TSPA is through the dose factors that are the input to the TSPA model.

Table 1-1. Biosphere-Related Features, Events, and Processes Implicitly Included in TSPA through the Use of Biosphere Dose Conversion Factors for the Volcanic Ash Exposure Scenario

FEP Name	LA FEP Number
Ashfall	1.2.04.07.0A
Climate change	1.3.01.00.0A
Soil type	2.3.02.01.0A
Radionuclide accumulation in soils	2.3.02.02.0A
Soil and sediment transport in the biosphere	2.3.02.03.0A
Precipitation	2.3.11.01.0A
Biosphere characteristics	2.3.13.01.0A
Radionuclide alteration during biosphere transport	2.3.13.02.0A
Human characteristics (physiology, metabolism)	2.4.01.00.0A
Human lifestyle	2.4.04.01.0A
Dwellings	2.4.07.00.0A
Wild and natural land and water use	2.4.08.00.0A
Agricultural land use and irrigation	2.4.09.01.0B
Animal farms and fisheries	2.4.09.02.0A
Urban and industrial land and water use	2.4.10.00.0A
Radioactive decay and ingrowth	3.1.01.01.0A
Atmospheric transport of contaminants	3.2.10.00.0A
Contaminated drinking water, foodstuffs and drugs	3.3.01.00.0A
Plant uptake	3.3.02.01.0A
Animal uptake	3.3.02.02.0A
Contaminated non-food products and exposure	3.3.03.01.0A
Ingestion	3.3.04.01.0A
Inhalation	3.3.04.02.0A
External exposure	3.3.04.03.0A
Radiation doses	3.3.05.01.0A
Radon and radon daughter exposure	3.3.08.00.0A

Source: DTN: MO0407SEPFEPLA.000 (DIRS 170760).

Table 1-2. Features, Events, and Processes Related to Inhalation Dose Factors

FEP Number [a]	FEP Name [a]	Description of FEP Relationship to Dose Factors
1.2.04.07.0A	Ashfall	Volcanic ash is the source of inhalation exposure during volcanic eruption. Inhalation dose is proportional to activity concentration in the airborne ash (Equation 6.3-2).
2.4.01.00.0A	Human characteristics (physiology, metabolism)	Physiology and metabolism of the human receptor were considered in developing the values of breathing rates and dose conversion factors for inhalation, which are used as input to calculate the values of dose factors (Equation 6.3-3).
2.4.04.01.0A	Human lifestyle	Lifestyles and characteristics of people living in Amargosa Valley were considered in developing the values of population proportions and exposure times, which are used as input to calculate the values of dose factors (Equation 6.3-3).
2.4.07.00.0A	Dwellings	Dwellings produce mitigating effect on inhalation dose, which is considered in the value of the indoor reduction factor for activity concentration in air, which is used to calculate the values of dose factors (Equation 6.3-3).
3.1.01.01.0A	Radioactive decay and ingrowth	Contribution from long-lived and short-lived decay products of primary radionuclides is included in the values of dose factors, primarily through the use of effective dose conversion factors for inhalation (Table 6.3-1) and also through including long-lived decay products in the dose factor for a primary radionuclide.
3.2.10.00.0A	Atmospheric transport of contaminants	Although not directly included in the development of the dose factors, atmospheric transport of radionuclides and the process of deposition of contaminated ash on the ground are inherently included in the calculation of the inhalation dose associated with the eruption phase (Section 6.3).
3.3.04.02.0A	Inhalation	Dose factors are used in evaluating exposure of the receptor arising from inhalation of contaminated resuspended particles (Equation 6.3-2).
3.3.05.01.0A	Radiation doses	Radiation doses arising from inhalation exposure during volcanic eruption will be evaluated in TSPA using dose factors developed in this analysis (section 6.3).

[a] Source: DTN: MO0407SEPFEPLA.000 (DIRS 170760).

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2. QUALITY ASSURANCE

This analysis involved development of data to support performance assessment, as identified in the technical work plan (BSC 2004 [DIRS 169573]), and thus, it was a quality affecting activity in accordance with AP-2.27Q, *Planning for Science Activities*. Approved quality assurance (QA) procedures identified in the TWP (BSC 2004 [DIRS 169573], Section 4) were used to conduct and document the activities described in this report. Specifically, the procedure governing development of this document was AP-SIII.9Q, *Scientific Analyses*. Electronic data used in this analysis were controlled in accordance with methods specified in the TWP (BSC 2004 [DIRS 169573], Section 8).

The natural barriers and items identified in the *Q-List* (BSC 2004 [DIRS 168361]) are not pertinent to this analysis. A Safety Category per AP-2.22Q, *Classification Analyses and Maintenance of the Q-List*, is not applicable.

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3. USE OF SOFTWARE

This analysis was performed using the verified and validated model, ERMYN, described in the *Biosphere Model Report* (BSC 2004 [DIRS 169460]). The model files were obtained from the Model Warehouse (DTN: MO0306MWDBGSMF.001 [DIRS 163816]). The model runs were conducted using the GoldSim Graphical Simulation Environment, a graphical, object-oriented computer program for carrying out dynamic, probabilistic simulations (GoldSim Technology Group 2002 [DIRS 160643]).

The analysis was conducted using two versions of software qualified under the Office of Civilian Radioactive Waste Management, QA program, for use on the Yucca Mountain Project.

- GoldSim V7.50.100, STN: 10344-7.5.100-00 (BSC 2003 [DIRS 161572])
- GoldSim V8.01, Service Pack (SP) 4, STN: 10344-8.01SP4-00 (BSC 2004 [DIRS 169695])

The software was appropriate for the application of running ERMYN model, which was implemented using GoldSim software, as described in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.9). GoldSim was used within the range of validation in accordance with procedure LP-SI.11Q-BSC, *Software Management*.

Both versions of GoldSim were installed by Software Configuration Management on a DELL Precision Workstation 530 computer (CPU# 151554) and run under the Windows 2000 operating system. The GoldSim files generated in this analysis are shown in Appendix A. The original verification of the model was performed using GoldSim V7.50.100. Verification of the model for the use with GoldSim V8.01 SP4 is described in Appendix E.

In addition, the commercial off-the-shelf product Microsoft® Excel 2000 (Version 9.0.3821 SR-1) was used for data reduction. Standard functions of that software were used to calculate values included in tables in Section 6. The use of those functions, including formulas or algorithms, inputs, and outputs are described in Appendix B.

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4. INPUTS

4.1 DIRECT INPUTS

4.1.1 Calculation of Biosphere Dose Conversion Factors

The inputs to this analysis are listed in Tables 4.1-1 to 4.1-4. Input parameter values and distributions were generated specifically for the biosphere model input and are appropriate for their intended use. The appropriateness for the intended use in this analysis and uncertainty in the input parameters is discussed in detail in the individual analysis reports that document parameter development (BSC 2004 [DIRS 169671]; BSC 2004 [DIRS 169672]; BSC 2004 [DIRS 169673]; BSC 2004 [DIRS 169458]; and BSC 2004 [DIRS 169459]).

The parameters were used as input for the ERMYN model for the volcanic ash exposure scenario, which is included in DTN: MO0306MWDBGSMF.001 [DIRS 163816]. The half-lives and branching fractions for radionuclides included in the biosphere model are listed in Table 4.1-2. Dose conversion factors for inhalation and ingestion for use in the biosphere model are shown in Table 4.1-3. Dose coefficients for exposure to contaminated soil are shown in Table 4.1-4.

The output of Revision 02 of this analysis (DTN: MO0307MWDDEBDC.001 [DIRS 164616]) is also a direct input to this analysis. This DTN is re-qualified within this analysis (see Appendix C) using a corroborating data approach as a qualification method per AP-SIII.2Q, *Qualification of Unqualified Data*. The Data Qualification Plan is included in Appendix D.

In the qualification process, DTN: MO0307MWDDEBDC.001 [DIRS 164616] is compared with the results of biosphere modeling generated in this analysis to determine the impact of software and input changes and to qualify the data. The software change involves the use of GoldSim V8.01 SP4 with a corrected Latin Hypercube sampling method. The input differences involve small changes in the values of several input parameters between the previous revision of this analysis (BSC 2003 [DIRS 163958]) and the current revision. Table 4.1-5 lists the input DTNs used by both analyses and summarizes differences between the inputs.

The direct inputs described in this section were used in Sections 6.2 and in Appendix C to calculate BDCFs for the volcanic ash exposure scenario.

Additional inputs were taken from the textbook references (sources of established fact data) to help with the statistical analysis of the results. Specifically, Steel and Torrie (1980 [DIRS 150857], pp. 278 to 279) was used as a source of statistical tests of hypotheses and Lide and Frederikse (1997 [DIRS 103178], p. A-105) was used as a source of percentage points for the Student-t distribution.

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
SURFACE SOIL SUBMODEL								
Radionuclide concentration in ash deposited on ground surface		Fixed	Bq/m^2	1	–	–	–	Source of contamination
Radionuclide half-life and branching fraction		Fixed	See Table 4.1-2	See Table 4.1-2	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]
Soil bulk density		Triangular	kg/m^3	1500	–	1300	1700	MO0407SPASRPBM.002 [DIRS 170755]
Surface soil depth (tillage depth)		Uniform	m	–	–	0.05	0.30	MO0403SPAAEIBM.002 [DIRS 169392]
Ash bulk density		Fixed	kg/m^3	1000	–	–	–	MO0407SPASRPBM.002 [DIRS 170755]
Thickness of ash deposited on the ground		–	–	–	–	–	–	Calculated in TSPA model
Critical thickness for the resuspension		Uniform	mm	–	–	1	3	MO0406SPAETPBM.002 [DIRS 170150]
AIR SUBMODEL								
Mass loading for crops		Triangular	mg/m^3	0.24	–	0.050	0.600	MO0407SPAINEXI.002 [DIRS 170597]
Mass loading for receptor environments at nominal condition	Active outdoors	Triangular	mg/m^3	5.00	–	1.000	10.000	MO0407SPAINEXI.002 [DIRS 170597]
	Inactive outdoors			0.06	–	0.025	0.100	
	Active indoors			0.10	–-	0.060	0.175	
	Asleep indoors			0.03	–	0.010	0.050	
Additional mass loading for receptor environments at post-volcanic condition	Active outdoors	Triangular	mg/m^3	2.50	–	0.000	5.000	MO0407SPAINEXI.002 [DIRS 170597]
	Inactive outdoors			0.06	–	0.025	0.200	
	Active indoors			0.10	–	0.060	0.175	
	Asleep indoors			0.03	–-	0.010	0.050	
Mass loading function f(t) = $S_0 e^{-\lambda t}$, with constant λ value	For initial ash depth < 10 mm	Triangular	1/yr	0.33	–	0.2	2.0	MO0407SPAINEXI.002 [DIRS 170597] Input to TSPA model
	For initial ash depth ≥ 10 mm			0.20	–	0.125	1.0	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Enhancement factor	Active outdoors	Cumulative	–	–	–	2.8 4.4 8.4	0% 50% 100%	MO0407SPASRPBM.002 [DIRS 170755]
	Inactive outdoors Active indoors Asleep indoors	Cumulative	–	–	–	0.21 0.7 1.04	0% 50% 100%	
Ratio of Rn-222 concentration in air to flux density from soil		Fixed	$(Bq\ m^{-3})/(Bq\ m^{-2}\ s^{-1})$	300	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
PLANT SUBMODEL								
Soil-to-plant transfer factor for leafy vegetables	Strontium	Lognormal[b]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	1.7E+00	2.0	2.9E-01	1.0E+01	MO0406SPAETPBM.002 [DIRS 170150]
	Technetium			4.6E+01	2.6	3.8E+00	5.5E+02	
	Tin			3.8E-02	2.0	6.4E-03	2.3E-01	
	Cesium			8.5E-02	2.5	7.7E-03	9.4E-01	
	Lead			1.5E-02	4.6	3.0E-04	7.7E-01	
	Radium			6.8E-02	2.7	5.1E-03	9.2E-01	
	Actinium			4.3E-03	2.0	7.2E-04	2.6E-02	
	Thorium			4.3E-03	2.8	3.2E-04	5.9E-02	
	Protactinium			4.6E-03	3.8	1.4E-04	1.4E-01	
	Uranium			1.1E-02	2.0	1.8E-03	6.6E-02	
	Neptunium			5.9E-02	4.4	1.3E-03	2.6E+00	
	Plutonium			2.9E-04	2.0	4.9E-05	1.7E-03	
	Americium			1.2E-03	2.5	1.2E-04	1.3E-02	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Soil-to-plant transfer factor for other vegetables	Strontium	Lognormal[b]	(Bq/kg$_{plant}$)/(Bq/kg$_{soil}$)	7.9E-01	2.0	1.4E-01	4.5E+00	MO0406SPAETPBM.002 [DIRS 170150]
	Technetium			4.4E+00	3.7	1.5E-01	1.2E+02	
	Tin			1.5E-02	3.6	5.3E-04	4.0E-01	
	Cesium			5.0E-02	2.0	8.4E-03	3.0E-01	
	Lead			9.0E-03	3.1	5.0E-04	1.6E-01	
	Radium			1.2E-02	5.3	1.6E-04	8.6E-01	
	Actinium			1.1E-03	4.9	1.8E-05	6.6E-02	
	Thorium			4.4E-04	5.6	5.3E-06	3.6E-02	
	Protactinium			1.1E-03	10.0	3.0E-06	4.3E-01	
	Uranium			6.0E-03	2.8	4.2E-04	8.5E-02	
	Neptunium			3.1E-02	4.9	5.0E-04	1.9E+00	
	Plutonium			1.9E-04	2.0	3.3E-05	1.1E-03	
	Americium			4.0E-04	2.6	3.5E-05	4.6E-03	
Soil-to-plant transfer factor for fruit	Strontium	Lognormal[b]	(Bq/kg$_{plant}$)/(Bq/kg$_{soil}$)	2.9E-01	2.3	3.6E-02	2.4E+00	MO0406SPAETPBM.002 [DIRS 170150]
	Technetium			4.3E+00	4.6	8.7E-02	2.1E+02	
	Tin			1.5E-02	3.6	5.3E-04	4.0E-01	
	Cesium			5.6E-02	2.8	3.8E-03	8.1E-01	
	Lead			1.2E-02	3.3	5.8E-04	2.6E-01	
	Radium			7.3E-03	4.3	1.6E-04	3.2E-01	
	Actinium			8.5E-04	3.4	3.7E-05	2.0E-02	
	Thorium			2.9E-04	4.9	4.8E-06	1.7E-02	
	Protactinium			1.1E-03	10.0	3.0E-06	4.3E-01	
	Uranium			6.3E-03	2.9	3.9E-04	1.0E-01	
	Neptunium			3.4E-02	6.9	2.3E-04	5.0E+00	
	Plutonium			1.8E-04	3.4	7.8E-06	4.2E-03	
	Americium			5.4E-04	2.3	6.5E-05	4.5E-03	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Soil-to-plant transfer factor for grain	Strontium	Lognormal[b]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	1.7E-01	2.0	2.8E-02	1.0E+00	MO0406SPAETPBM.002 [DIRS 170150]
	Technetium			1.6E+00	4.3	3.8E-02	6.8E+01	
	Tin			9.2E-03	2.0	1.5E-03	5.5E-02	
	Cesium			2.0E-02	2.2	2.7E-03	1.6E-01	
	Lead			5.5E-03	2.1	8.2E-04	3.8E-02	
	Radium			3.1E-03	4.0	8.8E-05	1.1E-01	
	Actinium			5.4E-04	2.9	3.6E-05	8.0E-03	
	Thorium			1.7E-04	5.2	2.4E-06	1.2E-02	
	Protactinium			9.5E-04	7.2	5.9E-06	1.5E-01	
	Uranium			1.1E-03	3.6	4.1E-05	3.1E-02	
	Neptunium			4.4E-03	6.9	3.1E-05	6.3E-01	
	Plutonium			1.9E-05	4.2	4.8E-07	7.8E-04	
	Americium			7.5E-05	3.2	3.8E-06	1.5E-03	
Soil-to-plant transfer factor for forage crops	Strontium	Lognormal[b]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	2.1E+00	2.1	3.2E-01	1.3E+01	MO0406SPAETPBM.002 [DIRS 170150]
	Technetium			2.7E+01	2.7	2.1E+00	3.5E+02	
	Tin			1.6E-01	5.8	1.7E-03	1.5E+01	
	Cesium			1.3E-01	3.3	6.3E-03	2.8E+00	
	Lead			1.8E-02	7.0	1.2E-04	2.8E+00	
	Radium			8.2E-02	3.0	4.9E-03	1.4E+00	
	Actinium			1.7E-02	5.4	2.2E-04	1.3E+00	
	Thorium			1.0E-02	4.2	2.5E-04	3.9E-01	
	Protactinium			1.9E-02	6.7	1.4E-04	2.5E+00	
	Uranium			1.7E-02	6.1	1.6E-04	1.9E+00	
	Neptunium			5.8E-02	5.6	6.8E-04	4.9E+00	
	Plutonium			1.0E-03	10.0	2.7E-06	3.9E-01	
	Americium			2.1E-03	10.0	5.5E-06	7.9E-01	
Correlation coefficient for transfer factors and solid-liquid partition coefficients		Fixed	–	–0.8	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Dry-to-wet weight ratio	Leafy vegetables	Cumulative	kg_{dry}/kg_{wet}	–	–	0.041 0.054 0.060 0.078 0.081 0.084 0.093	0% 17% 33% 50% 67% 83% 100%	MO0403SPAAEIBM.002 [DIRS 169392]
	Other vegetables	Cumulative	kg_{dry}/kg_{wet}	–	–	0.035 0.063 0.078 0.08 0.103 0.122 0.240	0% 17% 33% 50% 67% 83% 100%	
	Fruit	Cumulative	kg_{dry}/kg_{wet}	–	–	0.062 0.084 0.102 0.155 0.194	0% 25% 50% 75% 100%	
	Grain	Cumulative	kg_{dry}/kg_{wet}	–	–	0.891 0.896 0.906 0.918	0% 33% 67% 100%	
	Forage	Cumulative	kg_{dry}/kg_{wet}	–	–	0.182 0.227 0.238	0% 75% 100%	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name			Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Translocation factor		Leafy vegetables	Fixed	–	1.0	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
		Other vegetables	Cumulative	–	–	–	0.05	0 %	
		Fruit					0.1	50 %	
		Grain					0.3	100%	
		Forage	Fixed	–	1.0	–	–	–	
Weathering half-life			Cumulative	d	14	–	5 14 30	0 % 50 % 100 %	MO0406SPAETPBM.002 [DIRS 170150]
Crop growing time	Present-Day climate	Leafy vegetables	Fixed	d	75	–	–	–	MO0403SPAAEIBM.002 [DIRS 169392]
		Other vegetables			80	–	–	–	
		Fruit			160	–	–	–	
		Grain			200	–	–	–	
		Forage			75	–	–	–	
	Future climate	Leafy vegetables	Fixed	d	75	–	–	–	
		Other vegetables			100	–	–	–	
		Fruit			105	–	–	–	
		Grain			185	–	–	–	
		Forage			90	–	–	–	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Crop wet yield	Leafy vegetables	Cumulative	kg/m^2	–	–	1.08 1.46 1.78 2.01 2.98 3.25 3.83 7.79 7.85	0% 5% 20% 35% 50% 65% 80% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]
	Other vegetables	Cumulative	kg/m^2	–	–	2.8 3.37 3.56 3.64 4.92 5.15 6.61	0% 5% 28% 51% 72% 95% 100%	
	Fruit	Cumulative	kg/m^2	–	–	0.73 1.51 2.67 2.92 3.00 3.63 6.89	0% 5% 28% 51% 72% 95% 100%	
	Grain	Cumulative	kg/m^2	–	–	0.27 0.28 0.44 0.54 1.10 1.22	0% 5% 35% 65% 95% 100%	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Crop wet yield (continued)	Forage	Cumulative	kg/m^2	–	–	0.69 1.02 1.87 5.78 6.28	0% 5% 73% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]
Crop dry biomass	Leafy vegetables	Cumulative	kg/m^2	–	–	0.10 0.13 0.14 0.15 0.16 0.18 0.30 0.42 0.50	0% 5% 20% 35% 50% 65% 80% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]
	Other vegetables	Cumulative	kg/m^2	–	–	0.30 0.40 0.41 0.43 0.44 0.46 0.60	0% 5% 28% 51% 73% 95% 100%	
	Fruit	Cumulative	kg/m^2	–	–	0.10 0.56 0.60 0.65 0.68 1.30	0% 5% 35% 65% 95% 100%	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Crop dry biomass (continued)	Grain	Cumulative	kg/m^2	–	–	0.50	0%	MO0403SPAAEIBM.002 [DIRS 169392]
						0.61	5%	
						0.74	35%	
						1.20	65%	
						1.97	95%	
						2.20	100%	
	Forage	Cumulative	kg/m^2	–	–	0.10	0%	
						0.23	5%	
						0.34	73%	
						1.38	95%	
						1.50	100%	
Dry deposition velocity		Cumulative	m/s	–	–	3E-4	0 %	MO0406SPAETPBM.002 [DIRS 170150]
						1E-3	16 %	
						8E-3	50 %	
						3E-2	84 %	
						3E-1	100 %	
ANIMAL SUBMODEL								
Animal product transfer coefficients for meat	Strontium	Lognormal[b]	d/kg	1.4E-03	4.4	3.1E-05	6.2E-02	MO0406SPAETPBM.002 [DIRS 170150]
	Technetium			1.1E-03	7.2	6.9E-06	1.8E-01	
	Tin			1.9E-02	4.6	3.8E-04	9.9E-01	
	Cesium			2.4E-02	2.6	2.1E-03	2.7E-01	
	Lead			6.3E-04	2.6	5.4E-05	7.5E-03	
	Radium			8.1E-04	2.1	1.1E-04	5.7E-03	
	Actinium			7.9E-05	8.2	3.5E-07	1.8E-02	
	Thorium			1.1E-04	10.0	2.8E-07	4.0E-02	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Animal product transfer coefficients for meat (continued)	Protactinium	Lognormal[b]	d/kg	6.6E-05	10.0	1.8E-07	2.5E-02	MO0406SPAETPBM.002 [DIRS 170150]
	Uranium			4.8E-04	3.0	2.9E-05	7.8E-03	
	Neptunium			3.4E-04	8.8	1.3E-06	9.0E-02	
	Plutonium			1.3E-05	10.0	3.3E-08	4.7E-03	
	Americium			3.4E-05	9.0	1.2E-07	9.9E-03	
Animal product transfer coefficients for milk	Strontium	Lognormal[b]	d/L	1.7E-03	2.0	2.8E-04	1.0E-02	MO0406SPAETPBM.002 [DIRS 170150]
	Technetium			2.1E-03	6.0	2.0E-05	2.1E-01	
	Tin			1.1E-03	2.0	1.8E-04	6.3E-03	
	Cesium			7.7E-03	2.0	1.3E-03	4.6E-02	
	Lead			1.7E-04	3.0	1.0E-05	2.9E-03	
	Radium			5.8E-04	2.0	1.0E-04	3.4E-03	
	Actinium			7.6E-06	4.1	2.0E-07	2.9E-04	
	Thorium			4.4E-06	2.0	7.4E-07	2.6E-05	
	Protactinium			4.4E-06	2.0	7.4E-07	2.6E-05	
	Uranium			4.9E-04	2.0	8.1E-05	2.9E-03	
	Neptunium			6.3E-06	2.0	1.0E-06	3.9E-05	
	Plutonium			2.3E-07	7.7	1.2E-09	4.4E-05	
	Americium			1.6E-06	4.2	3.9E-08	6.3E-05	
Animal product transfer coefficients for poultry	Strontium	Lognormal[b]	d/kg	3.1E-02	5.8	3.4E-04	2.9E+00	MO0406SPAETPBM.002 [DIRS 170150]
	Technetium			6.3E-02	10.0	1.7E-04	2.4E+01	
	Tin			3.5E-02	10.0	9.4E-05	1.3E+01	
	Cesium			2.6E+00	9.8	7.2E-03	9.3E+02	
	Lead			2.5E-02	10.0	6.6E-05	9.3E+00	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Animal product transfer coefficients for poultry (continued)	Radium	Lognormal[b]	d/kg	1.7E-02	10.0	4.4E-05	6.3E+00	MO0406SPAETPBM.002 [DIRS 170150]
	Actinium			4.0E-03	2.0	6.7E-04	2.4E-02	
	Thorium			5.9E-03	8.0	2.7E-05	1.3E+00	
	Protactinium			3.0E-03	2.0	5.1E-04	1.8E-02	
	Uranium			2.4E-01	10.0	6.5E-04	9.2E+01	
	Neptunium			3.6E-03	2.0	6.0E-04	2.1E-02	
	Plutonium			1.2E-03	10.0	3.2E-06	4.6E-01	
	Americium			1.8E-03	10.0	4.8E-06	6.7E-01	
Animal product transfer coefficients for eggs	Strontium	Lognormal[b]	d/kg	2.7E-01	2.0	4.5E-02	1.6E+00	MO0406SPAETPBM.002 [DIRS 170150]
	Technetium			2.4E+00	2.0	4.0E-01	1.4E+01	
	Tin			8.7E-02	10.0	2.3E-04	3.3E+01	
	Cesium			3.5E-01	5.8	3.7E-03	3.3E+01	
	Lead			5.6E-02	10.0	1.5E-04	2.1E+01	
	Radium			3.9E-04	10.0	1.0E-06	1.5E-01	
	Actinium			2.9E-03	2.3	3.4E-04	2.5E-02	
	Thorium			3.5E-03	7.3	2.0E-05	5.9E-01	
	Protactinium			2.0E-03	2.0	3.4E-04	1.2E-02	
	Uranium			6.3E-01	2.5	6.0E-02	6.7E+00	
	Neptunium			3.4E-03	2.4	3.4E-04	3.3E-02	
	Plutonium			1.7E-03	7.4	9.7E-06	2.9E-01	
	Americium			4.9E-03	2.0	8.2E-04	2.9E-02	
Animal consumption rate of feed	Beef cattle	Uniform	kg/d	–	–	29	68	MO0406SPAETPBM.002 [DIRS 170150]
	Dairy cow			–	–	50	73	
	Poultry			–	–	0.12	0.4	
	Laying hen			–	–	0.12	0.4	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Animal consumption rate of water	Beef cattle	Fixed	L/d	60	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
	Dairy cow	Uniform		–	–	60	100	
	Poultry	Fixed		0.5	–	–	–	
	Laying hen	Fixed		0.5	–	–	–	
Animal consumption rate of soil	Beef cattle	Uniform	kg/d	–	–	0.4	1.0	MO0406SPAETPBM.002 [DIRS 170150]
	Dairy cow			–	–	0.8	1.1	
	Poultry			–	–	0.01	0.03	
	Laying hen			–	–	0.01	0.03	
EXTERNAL EXPOSURE SUBMODEL								
Population proportion	Outdoor workers	Uniform	%	–	–	2.9	10.7	MO0407SPACRBSM.002 [DIRS 170677]
	Indoor workers			–	–	Calculated	Calculated	
	Commuters			–	–	4.9	16.3	
	Non-workers			–	–	34.4	44.0	
Time spent by outdoor workers	Active outdoors	Lognormal[c]	hr/d	3.1	0.2	2.6	3.7	MO0407SPACRBSM.002 [DIRS 170677]
	Inactive outdoors			4.2	0.3	3.5	5.0	
	Active indoors			6.4	Calculated	–	–	
	Asleep indoors			8.3	0.1	8.0	8.6	
	Away			2.0	0.4	1.2	3.3	
Time spent by indoor workers	Active outdoors	Lognormal[c]	hr/d	0.3	0.1	0.1	0.7	
	Inactive outdoors			1.5	0.2	1.1	2.1	
	Active indoors			11.9	Calculated	–	–	
	Asleep indoors			8.3	0.1	8.0	8.6	
	Away			2.0	0.4	1.2	3.3	
Time spent by commuters	Active outdoors	Lognormal[c]	hr/d	0.3	0.1	0.1	0.7	
	Inactive outdoors			2.0	0.2	1.5	2.6	
	Active indoors			5.1	Calculated	–	–	
	Asleep indoors			8.3	0.1	8.0	8.6	
	Away			8.3	0.6	6.9	10.0	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Time spent by non-workers	Active outdoors	Lognormal[c]	hr/d	0.3	0.1	0.1	0.7	MO0407SPACRBSM.002 [DIRS 170677]
	Inactive outdoors			1.2	0.2	0.8	1.8	
	Active indoors			12.2	Calculated	–	–	
	Asleep indoors			8.3	0.1	8.0	8.6	
	Away			2.0	0.4	1.2	3.3	
Building shielding factor	Sr-90D	Fixed	–	0.4	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]
	Tc-99			0.2	–	–	–	
	Sn-126D			0.4	–	–	–	
	Cs-137D			0.4	–	–	–	
	Pu-242			0.1	–	–	–	
	U-238D			0.4	–	–	–	
	Pu-238			0.1	–	–	–	
	U-234			0.2	–	–	–	
	Th-230			0.3	–	–	–	
	Ra-226D			0.4	–	–	–	
	Pb-210D			0.4	–	–	–	
	Pu-240			0.1	–	–	–	
	U-236			0.1	–	–	–	
	Th-232			0.2	–	–	–	
	Ra-228D			0.4	–	–	–	
	U-232			0.3	–	–	–	
	Th-228D			0.4	–	–	–	
	Am-243D			0.4	–	–	–	
	Pu-239			0.3	–	–	–	
	U-235D			0.4	–	–	–	
	Pa-231			0.4	–	–	–	
	Ac-227D			0.4	–	–	–	
	Am-241			0.2	–	–	–	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
	Np-237D			0.4	–	–	–	
	U-233			0.4	–	–	–	
	Th-229D			0.4	–	–	–	
Dose coefficient for exposure to contaminated ground surface		Fixed	(Sv/yr)/(Bq/m^2)	See Table 4.1-4	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]
INHALATION SUBMODEL								
Breathing rate	Active outdoors	Fixed	m^3/hr	1.57	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]
	Inactive outdoors			1.08	–	–	–	
	Active indoors			1.08	–	–	–	
	Asleep indoors			0.39	–	–	–	
	Away			1.08 [d]	–	–	–	
Dose conversion factor for inhalation		Fixed	Sv/Bq	See Table 4.1-3	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]
Equilibrium factor for ^{222}Rn decay products	Outdoors	Uniform	–	–	–	0.5	0.7	MO0406SPAETPBM.002 [DIRS 170150]
	Indoors	Uniform	–	–	–	0.3	0.5	
Dose conversion factor for inhalation of ^{222}Rn decay products		Fixed	Sv/Bq	1.33E-08	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (Continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
INGESTION SUBMODEL								
Consumption rate of locally produced food	Leafy vegetables	Lognormal[c]	kg/yr	3.78	0.88	–	–	MO0407SPACRBSM.002 [DIRS 170677]
	Other vegetables			4.73	0.67	–	–	
	Fruit			12.68	1.36	–	–	
	Grain			0.23	0.11	–	–	
	Meat			2.85	0.65	–	–	
	Milk			4.66	1.68	–	–	
	Poultry			0.42	0.13	–	–	
	Eggs			5.30	0.83	–	–	
Inadvertent soil ingestion rate		Cumulative	mg/d	–	–	50 100 200	0% 50% 100%	MO0407SPACRBSM.002 [DIRS 170677]
Dose conversion factor for ingestion		Fixed	Sv/Bq	See Table 4.1-3	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]

[a] SD = standard deviation; SE = standard error; CD = cumulative distribution.
[b] Lognormal distribution defined using geometric mean and geometric standard deviation.
[c] Lognormal distributions defined using arithmetic mean and arithmetic standard deviation.
[d] Breathing rate away (not in contaminated area) has no effect on the results of BDCF calculations. Any value can be used.

Table 4.1-2. Primary Radionuclides and Their Decay Products Included in the Biosphere Model for the Volcanic Ash Exposure Scenario

Primary Radionuclide	Short-lived Decay Product [a]	Branching Fraction, %	Half-life
Strontium-90 (^{90}Sr)		100	2.912E+01 yr
	Yttrium-90 (^{90}Y)	100	6.40E+01 hr
Technetium-99 (^{99}Tc)		100	2.13E+05 yr
Tin-126 (^{126}Sn)		100	1.0E+05 yr
	Antimony-126m (^{126m}Sb)	100	1.90E+01 min
	Antimony-126 (^{126}Sb)	14	1.24E+01 d
Cesium-137 (^{137}Cs)		100	3.00E+01 yr
	Barium-137m (^{137m}Ba)	94.60	2.552E+00 min
Thorium Series (4n)			
Plutonium-240 (^{240}Pu)		100	6.537E+03 yr
Uranium-236 (^{236}U)		100	2.3415E+07 yr
Thorium-232 (^{232}Th)		100	1.405E+10 yr
Radium-228 (^{228}Ra)		100	5.75E+00 yr
	Actinium-228 (^{228}Ac)	100	6.13E+00 hr
Uranium-232 (^{232}U)		100	7.2E+01 yr
Thorium-228 (^{228}Th)		100	1.9131E+00 yr
	Radium-224 (^{224}Ra)	100	3.66E+00 d
	Radon-220 (^{220}Rn)	100	5.56E+01 s
	Polonium-216 (^{216}Po)	100	1.5E-01 s
	Lead-212 (^{212}Pb)	100	1.064E+01 hr
	Bismuth-212 (^{212}Bi)	100	6.055E+01 min
	Polonium-212 (^{212}Po)	64.07	3.05E-07 s
	Thallium-208 (^{208}Tl)	35.93	3.07E+00 min
Neptunium Series (4n+1)			
Americium-241 (^{241}Am)		100	4.322E+02 yr
Neptunium-237 (^{237}Np)		100	2.14E+06 yr
	Protactinium-233 (^{233}Pa)	100	2.70E+01 d
Uranium-233 (^{233}U)		100	1.585E+05 yr
Thorium-229 (^{229}Th)		100	7.340E+03 yr
	Radium-225 (^{225}Ra)	100	1.48E+01 d
	Actinium-225 (^{225}Ac)	100	1.00E+01 d
	Francium-221 (^{221}Fr)	100	4.8E+00 min
	Astatine-217 (^{217}At)	100	3.23E-02 s
	Bismuth-213 (^{213}Bi)	100	4.565E+01 min
	Polonium-213 (^{213}Po)	97.84	4.2E-06 s
	Thallium-209 (^{209}Tl)	2.16	2.20E+00 min
	Lead-209 (^{209}Pb)	100	3.253E+00 hr

Table 4.1-2. Primary Radionuclides and Their Decay Products Included in the Biosphere Model for the Volcanic Ash Exposure Scenario (Continued)

Primary Radionuclide	Short-lived Decay Product [a]	Branching Fraction, %	Half-life
Uranium Series (4n + 2)			
Plutonium-242 (^{242}Pu)		100	3.763E+05 yr
Uranium-238 (^{238}U)		100	4.468E+09 yr
	Thorium-234 (^{234}Th)	100	2.410E+01 d
	Protactinium-234m (^{234m}Pa)	99.80	1.17E+00 min
	Protactinium-234 (^{234}Pa)	0.33	6.70E+00 hr
Plutonium-238 (^{238}Pu)		100	8.774E+01 yr
Uranium-234 (^{234}U)		100	2.445E+05 yr
Thorium-230 (^{230}Th)		100	7.7E+04 yr
Radium-226 (^{226}Ra)		100	1.600E+03 yr
	Radon-222 (^{222}Rn)	100	3.8235E+00 d
	Polonium-218 (^{218}Po)	100	3.05E+00 min
	Lead-214 (^{214}Pb)	99.98	2.68E+01 min
	Astatine-218 (^{218}At)	0.02	2.E+00 s
	Bismuth-214 (^{214}Bi)	100	1.99E+01 min
	Polonium-214 (^{214}Po)	99.98	1.643E-04 s
	Thallium-210 (^{210}Tl)	0.02	1.3E+00 min [b]
Lead-210 (^{210}Pb)		100	2.23E+01 yr
	Bismuth-210 (^{210}Bi)	100	5.012E+00 d
	Polonium-210 (^{210}Po)	100	1.3838 E+02 d
Actinium Series (4n + 3)			
Americium-243 (^{243}Am)		100	7.380E+03 yr
	Neptunium-239 (^{239}Np)	100	2.355E+00 d
Plutonium-239 (^{239}Pu)		100	2.4065E+04 yr
Uranium-235 (^{235}U)		100	7.038E+08 yr
	Thorium-231 (^{231}Th)	100	2.552E+01 hr
Protactinium-231 (^{231}Pa)		100	3.276E+04 yr
Actinium-227 (^{227}Ac)		100	2.1773E+01 yr
	Thorium-227 (^{227}Th)	98.62	1.8718E+01 d
	Francium-223 (^{223}Fr)	1.38	2.18E+01 min
	Radium-223 (^{223}Ra)	100	1.1434E+01 d
	Radon-219 (^{219}Rn)	100	3.96E+00 s
	Polonium-215 (215Po)	100	1.78E-03 s
	Lead-211 (211Pb)	100	3.61E+01 min
	Bismuth-211 (211Bi)	100	2.14E+00 min
	Thallium-207 (207Tl)	99.72	4.77E+00 min
	Polonium-211 (211Po)	0.28	5.16E-01 s

Source: MO0407SPACRBSM.002 [DIRS 170677].

[a] Short-lived decay products of primary radionuclides are assumed to be in secular equilibrium with their parents (Section 6.1.1).

Table 4.1-3. Dose Conversion Factors for Inhalation and Ingestion of Radionuclides of Interest

Primary Radionuclide	Short-lived Decay Product	Dose Conversion Factors (Sv/Bq)	
		Inhalation	Ingestion
Strontium-90 (^{90}Sr)		6.47E-08	3.85E-08
	Yttrium-90 (^{90}Y)	2.28E-09	2.91E-09
Technetium-99 (^{99}Tc)		2.25E-09	3.95E-10
Tin-126 (^{126}Sn)		2.69E-08	5.27E-09
	Antimony-126m (^{126m}Sb)	9.17E-12	2.54E-11
	Antimony-126 (^{126}Sb)	3.17E-09	2.89E-09
Cesium-137 (^{137}Cs)		8.63E-09	1.35E-08
	Barium-137m (^{137m}Ba)	–	–
Thorium Series (4n)			
Plutonium-240 (^{240}Pu)		1.16E-04	9.56E-07
Uranium-236 (^{236}U)		3.39E-05	7.26E-08
Thorium-232 (^{232}Th)		4.43E-04	7.38E-07
Radium-228 (^{228}Ra)		1.29E-06	3.88E-07
	Actinium-228 (^{228}Ac)	8.33E-08	5.85E-10
Uranium-232 (^{232}U)		1.78E-04	3.54E-07
Thorium-228 (^{228}Th)		9.23E-05	1.07E-07
	Radium-224 (^{224}Ra)	8.53E-07	9.89E-08
	Radon-220 (^{220}Rn)	–	–
	Polonium-216 (^{216}Po)	–	–
	Lead-212 (^{212}Pb)	4.56E-08	1.23E-08
	Bismuth-212 (^{212}Bi)	5.83E-09	2.87E-10
	Polonium-212 (^{212}Po)	–	–
	Thallium-208 (^{208}Tl)	–	–
Neptunium Series (4n+1)			
Americium-241 (^{241}Am)		1.20E-04	9.84E-07
Neptunium-237 (^{237}Np)		1.46E-04	1.20E-06
	Protactinium-233 (^{233}Pa)	2.58E-09	9.81E-10
Uranium-233 (^{233}U)		3.66E-05	7.81E-08
Thorium-229 (^{229}Th)		5.80E-04	9.54E-07
	Radium-225 (^{225}Ra)	2.10E-06	1.04E-07
	Actinium-225 (^{225}Ac)	2.92E-06	3.00E-08
	Francium-221 (^{221}Fr)	–	–
	Astatine-217 (^{217}At)	–	–
	Bismuth-213 (^{213}Bi)	4.63E-09	1.95E-10
	Polonium-213 (^{213}Po)	–	–
	Thallium-209 (^{209}Tl)	–	–
	Lead-209 (^{209}Pb)	2.56E-11	5.75E-11

Table 4.1-3. Dose Conversion Factors for Inhalation and Ingestion of Radionuclides of Interest (Continued)

Primary Radionuclide	Short-lived Decay Product	Dose Conversion Factors (Sv/Bq)	
		Inhalation	Ingestion
Uranium Series (4n + 2)			
Plutonium-242 (^{242}Pu)		1.11E-04	9.08E-07
Uranium-238 (^{238}U)		3.20E-05	6.88E-08
	Thorium-234 (^{234}Th)	9.47E-09	3.69E-09
	Protactinium-234m (^{234m}Pa)	–	–
	Protactinium-234 (^{234}Pa)	2.20E-10	5.84E-10
Plutonium-238 (^{238}Pu)		1.06E-04	8.65E-07
Uranium-234 (^{234}U)		3.58E-05	7.66E-08
Thorium-230 (^{230}Th)		8.80E-05	1.48E-07
Radium-226 (^{226}Ra)		2.32E-06	3.58E-07
	Radon-222 (^{222}Rn)	–	–
	Polonium-218 (^{218}Po)	–	–
	Lead-214 (^{214}Pb)	2.11E-09	1.69E-10
	Astatine-218 (^{218}At)	–	–
	Bismuth-214 (^{214}Bi)	1.78E-09	7.64E-11
	Polonium-214 (^{214}Po)	–	–
	Thallium-210 (^{210}Tl)	–	–
Lead-210 (^{210}Pb)		3.67E-06	1.45E-06
	Bismuth-210 (^{210}Bi)	5.29E-08	1.73E-09
	Polonium-210 (^{210}Po)	2.54E-06	5.14E-07
Actinium Series (4n + 3)			
Americium-243 (^{243}Am)		1.19E-04	9.79E-07
	Neptunium-239 (^{239}Np)	6.78E-10	8.82E-10
Plutonium-239 (^{239}Pu)		1.16E-04	9.56E-07
Uranium-235 (^{235}U)		3.32E-05	7.19E-08
	Thorium-231 (^{231}Th)	2.37E-10	3.65E-10
Protactinium-231 (^{231}Pa)		3.47E-04	2.86E-06
Actinium-227 (^{227}Ac)		1.81E-03	3.80E-06
	Thorium-227 (^{227}Th)	4.37E-06	1.03E-08
	Francium-223 (^{223}Fr)	1.68E-09	2.33E-09
	Radium-223 (^{223}Ra)	2.12E-06	1.78E-07
	Radon-219 (^{219}Rn)	–	–
	Polonium-215 (^{215}Po)	–	–
	Lead-211 (^{211}Pb)	2.35E-09	1.42E-10
	Bismuth-211 (^{211}Bi)	–	–
	Thallium-207 (^{207}Tl)	–	–
	Polonium-211 (^{211}Po)	–	–

Source: MO0407SPACRBSM.002 [DIRS 170677].

NOTES: DCFs are in units of Sv/Bq.
1 Sv = 100 rem.
1 Ci = 3.7×10^{10} Bq.

Table 4.1-4. Dose Coefficients for Exposure to Contaminated Soil Surface for Radionuclides of Interest

Primary Radionuclide	Short-lived Decay Product	Dose Coefficient Sv/s per Bq/m^2
Strontium-90 (^{90}Sr)		2.84E-19
	Yttrium-90 (^{90}Y)	5.32E-18
Technetium-99 (^{99}Tc)		7.80E-20
Tin-126 (^{126}Sn)		5.47E-17
	Antimony-126m (^{126m}Sb)	1.52E-15
	Antimony-126 (^{126}Sb)	2.78E-15
Cesium-137 (^{137}Cs)		2.85E-19
	Barium-137m (^{137m}Ba)	5.86E-16
Thorium Series (4n)		
Plutonium-240 (^{240}Pu)		8.03E-19
Uranium-236 (^{236}U)		6.50E-19
Thorium-232 (^{232}Th)		5.51E-19
Radium-228 (^{228}Ra)		0.00E+00
	Actinium-228 (^{228}Ac)	9.28E-16
Uranium-232 (^{232}U)		1.01E-18
Thorium-228 (^{228}Th)		2.35E-18
	Radium-224 (^{224}Ra)	9.57E-18
	Radon-220 (^{220}Rn)	3.81E-19
	Polonium-216 (^{216}Po)	1.65E-20
	Lead-212 (^{212}Pb)	1.43E-16
	Bismuth-212 (^{212}Bi)	1.79E-16
	Polonium-212 (^{212}Po)	0.00E+00
	Thallium-208 (^{208}Tl)	2.98E-15
Neptunium Series (4n+1)		
Americium-241 (^{241}Am)		2.75E-17
Neptunium-237 (^{237}Np)		2.87E-17
	Protactinium-233 (^{233}Pa)	1.95E-16
Uranium-233 (^{233}U)		7.16E-19
Thorium-229 (^{229}Th)		8.54E-17
	Radium-225 (^{225}Ra)	1.33E-17
	Actinium-225 (^{225}Ac)	1.58E-17
	Francium-221 (^{221}Fr)	2.98E-17
	Astatine-217 (^{217}At)	3.03E-19
	Bismuth-213 (^{213}Bi)	1.32E-16
	Polonium-213 (^{213}Po)	0.00E+00
	Thallium-209 (^{209}Tl)	1.90E-15
	Lead-209 (^{209}Pb)	3.01E-19

Table 4.1-4. Dose Coefficients for Exposure to Contaminated Soil Surface for Radionuclides of Interest (Continued)

Primary Radionuclide	Short-lived Decay Product	Dose Coefficient Sv/s per Bq/m^2
Uranium Series (4n + 2)		
Plutonium-242 (^{242}Pu)		6.67E-19
Uranium-238 (^{238}U)		5.51E-19
	Thorium-234 (^{234}Th)	8.32E-18
	Protactinium-234m (^{234m}Pa)	1.53E-17
	Protactinium-234 (^{234}Pa)	1.84E-15
Plutonium-238 (^{238}Pu)		8.38E-19
Uranium-234 (^{234}U)		7.48E-19
Thorium-230 (^{230}Th)		7.50E-19
Radium-226 (^{226}Ra)		6.44E-18
	Radon-222 (^{222}Rn)	3.95E-19
	Polonium-218 (^{218}Po)	8.88E-21
	Lead-214 (^{214}Pb)	2.44E-16
	Astatine-218 (^{218}At)	4.18E-18
	Bismuth-214 (^{214}Bi)	1.41E-15
	Polonium-214 (^{214}Po)	8.13E-20
	Thallium-210 (^{210}Tl)	–
Lead-210 (^{210}Pb)		2.48E-18
	Bismuth-210 (^{210}Bi)	1.05E-18
	Polonium-210 (^{210}Po)	8.29E-21
Actinium Series (4n + 3)		
Americium-243 (^{243}Am)		5.35E-17
	Neptunium-239 (^{239}Np)	1.63E-16
Plutonium-239 (^{239}Pu)		3.67E-19
Uranium-235 (^{235}U)		1.48E-16
	Thorium-231 (^{231}Th)	1.85E-17
Protactinium-231 (^{231}Pa)		4.07E-17
Actinium-227 (^{227}Ac)		1.57E-19
	Thorium-227 (^{227}Th)	1.04E-16
	Francium-223 (^{223}Fr)	5.65E-17
	Radium-223 (^{223}Ra)	1.28E-16
	Radon-219 (^{219}Rn)	5.49E-17
	Polonium-215 (^{215}Po)	1.74E-19
	Lead-211 (^{211}Pb)	5.08E-17
	Bismuth-211 (^{211}Bi)	4.58E-17
	Thallium-207 (^{207}Tl)	3.76E-18
	Polonium-211 (^{211}Po)	7.61E-18

Source: MO0407SPACRBSM.002 [DIRS 170677].

Table 4.1-5. Comparison of Input Parameters for This and the Previous Revision of the Analysis

Parameter Name and Change Description	Previous Revision		Current Revision	
	DTN	Parameter Value and Percentile for Cumulative Distribution	DTN	Parameter Value and Percentile for Cumulative Distribution
Agricultural and Environmental Input Parameters				
Parameters whose value changed are not used in the volcanic ash exposure scenario	MO0306SPAAEIBM.001 [DIRS 163812]	N/A	MO0403SPAAEIBM.002 [DIRS 169392]	N/A
Environmental Transport Input Parameters				
Cesium transfer factor for leafy vegetables (both climates)	MO0306SPAETPBM.001 [DIRS 163814]	Lognormal distribution [a] GM = 1.2E-01 GSD = 2.5 Minimum = 1.2E-02 Maximum = 1.2E+00	MO0406SPAETPBM.002 [DIRS 170150]	Lognormal distribution GM = 8.5E-02 GSD = 2.5 Minimum = 7.7E-03 Maximum = 9.4E-01
Cesium transfer coefficient for eggs	MO0306SPAETPBM.001 [DIRS 163814]	Lognormal distribution [a] GM = 5.9E-01 GSD = 2.3 Minimum = 7.2E-02 Maximum = 4.8E+00	MO0406SPAETPBM.002 [DIRS 170150]	Lognormal distribution [a] GM = 3.5E-01 GSD = 5.8 Minimum = 3.7E-03 Maximum = 3.3E+01
Characteristics of the Receptor				
Half-life of Pu-238 [b]	MO0306SPACRBSM.001 [DIRS 163813]	87.74E+01 yr	MO0407SPACRBSM.002 [DIRS 170677]	8.774E+01 yr
Inhalation Exposure Input Parameters				
Maximum value for volcanic mass loading for asleep indoors environment	MO0305SPAINEXI.001 [DIRS 163808]	0.060 mg/m^3	MO0407SPAINEXI.002 [DIRS 170597]	0.050 mg/m^3
Soil-related Input Parameters				
The DTN change concerns description of parameter applicability for different climate states; parameter values remained the same	MO0305SPASRPBM.001 [DIRS 163815]	N/A	MO0407SPASRPBM.002 [DIRS 170755]	N/A

[a] GM = geometric mean, GSD = geometric standard deviation.
[b] Typographical error in the DTN; a correct value was used in the model.

4.1.2 Calculation of Inhalation Dose Factors for Volcanic Eruption

Inhalation dose factors for volcanic eruption were calculated using the relevant data presented in Table 4.1-1. In addition, average values of the estimated proportion of population for the volcanic scenario were used from MO0407SPACRBSM.002 [DIRS 170677] and are listed in Table 4.1-6.

Table 4.1-6. Population Proportion Values Used for Calculating Inhalation Dose Factors

Population group	Average Population Proportion
Non-workers	0.392
Commuters	0.125
Local outdoor workers	0.055
Local indoor workers	0.428

The data described above were used in Section 6.3.

4.2 CRITERIA

Three requirements from the *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275], Table 2-3) are applicable to this analysis (Table 4.2-1).

Table 4.2-1. Requirements Applicable to this Analysis

Requirement Number	Requirement Title	Related Regulation
PRD-002/T-015	Requirements for Performance Assessment	10 CFR 63.114
PRD-002/T-026	Required Characteristics of the Reference Biosphere	10 CFR 63.305
PRD-002/T-028	Required Characteristics of the Reasonably Maximally Exposed Individual	10 CFR 63.312

Source: Canori and Leitner 2003 [DIRS 166275], Table 2-3.

In addition to the requirements listed in Table 4.2-1, definition of terms in 10 CFR 63.2 and description of concepts in 10 CFR 63.102 [DIRS 156605] that are relevant to biosphere modeling are also applicable to this analysis.

Listed below are NRC acceptance criteria from Sections 2.2.1.2.13 (Redistribution of Radionuclides in Soil) and 2.2.1.3.14 (Biosphere Characteristics) of the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]), based on the requirements of 10 CFR 63.114, 63.305, and 63.312 [DIRS 156605], that were considered when modeling biosphere characteristics.

<u>**Acceptance Criteria from Section 2.2.1.3.13, Redistribution of Radionuclides in Soil**</u>

Acceptance Criterion 1, *System Description and Model Integration Are Adequate.*

(1) Total system performance assessment adequately incorporates important features, physical phenomena and couplings between different models, and uses consistent and appropriate

assumptions throughout the abstraction of redistribution of radionuclides in the soil abstraction process;

(2) The total system performance assessment model abstraction identifies and describes aspects of redistribution of radionuclides in soil that are important to repository performance, including the technical bases for these descriptions. For example, the abstraction should include modeling of the deposition of contaminated material in the soil and determination of the depth distribution of the deposited radionuclides;

(3) Relevant site features, events, and processes have been appropriately modeled in the abstraction of redistribution of radionuclides, from surface processes, and sufficient technical bases are provided; and

(4) Guidance in NUREG–1297 and NUREG–1298, or other acceptable approaches for peer reviews, is followed.

Acceptance Criterion 2, *Data Are Sufficient for Model Justification.*

(1) Behavioral, hydrological, and geochemical values used in the license application are adequately justified (e.g., irrigation and precipitation rates, erosion rates, radionuclide solubility values, etc.). Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided; and

(2) Sufficient data (e.g., field, laboratory, and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the abstraction of redistribution of radionuclides in soil in the total system performance assessment.

Acceptance Criterion 3, *Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.*

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, do not result in an under-representation of the risk estimate, and are consistent with the characteristics of the reasonably maximally exposed individual in 10 CFR Part 63;

(2) The technical bases for the parameter values and ranges in the total system performance assessment abstraction are consistent with data from the Yucca Mountain region, e.g., Amargosa Valley survey, studies of surface processes in the Fortymile Wash drainage basin, applicable laboratory testing, natural analogs, or other valid sources of data. For example, soil types, crop types, plow depths, and irrigation rates should be consistent with current farming practices, and data on the airborne particulate concentration should be based on the resuspension of appropriate material in a climate and level of disturbance similar to that which is expected to be found at the location of the reasonably maximally exposed individual, during the compliance time period;

(3) Uncertainty is adequately represented in parameters for conceptual models, process models, and alternative conceptual models considered in developing the total system performance assessment abstraction of redistribution of radionuclides in soil, either through sensitivity

analyses, conservative limits, or bounding values supported by data, as necessary. Correlations between input values are appropriately established in the total system performance assessment.

<u>Acceptance Criteria from Section 2.2.1.3.14, Biosphere Characteristics</u>

Acceptance Criterion 1, ***System Description and Model Integration Are Adequate.***

(3) Assumptions are consistent between the biosphere characteristics modeling and other abstractions. For example, the U.S. Department of Energy should ensure that the modeling of features, events, and processes, such as climate change, soil types, sorption coefficients, volcanic ash properties, and the physical and chemical properties of radionuclides are consistent with assumptions in other total system performance assessment abstractions; and

(4) Guidance in NUREG–1297 and NUREG–1298 or in other acceptable approaches for peer reviews, is followed.

Acceptance Criterion 2, ***Data Are Sufficient for Model Justification.***

(1) The parameter values used in the license application are adequately justified (e.g., behaviors and characteristics of the residents of the Town of Amargosa Valley, Nevada, characteristics of the reference biosphere, etc.) and consistent with the definition of the reasonably maximally exposed individual in 10 CFR Part 63. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided; and

(2) Data are sufficient to assess the degree to which features, events, and processes related to biosphere characteristics modeling have been characterized and incorporated in the abstraction. As specified in 10 CFR Part 63, the U.S. Department of Energy should ensure that the modeling of features, events, and processes, such as climate change, soil types, sorption coefficients, volcanic ash properties, and the physical and chemical properties of radionuclides are consistent with assumptions in other total system performance assessment abstractions.

Acceptance Criterion 3, ***Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.***

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, do not result in an under-representation of the risk estimate, and are consistent with the definition of the reasonably maximally exposed individual in 10 CFR Part 63;

(2) The technical bases for the parameter values and ranges in the abstraction, such as consumption rates, plant and animal uptake factors, mass-loading factors, and biosphere dose conversion factors, are consistent with site characterization data, and are technically defensible.

4.3 CODES, STANDARDS, AND REGULATIONS

No codes, standards, or regulations, other than those identified in the Project Requirements Document (Canori and Leitner 2003 [DIRS 166275], Table 2-3) and determined to be applicable, were used in this analysis.

5. ASSUMPTIONS

No assumptions were used in this analysis.

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6. SCIENTIFIC ANALYSIS DISCUSSION

The objectives of this analysis were to calculate:

1. The BDCFs for the volcanic ash exposure scenario – these BDCFs are used as input to the TSPA model and allow calculating the expected annual dose to the reasonably maximally exposed individual (RMEI) from a given concentration of radionuclides in surface soil and thickness of volcanic ash deposited on the ground. The dose to the RMEI is used to evaluate compliance with the individual protection standard (10 CFR 63.311 [DIRS 156605]).

2. The dose factors that can be used by TSPA to calculate the expected inhalation dose accrued during the period of deposition of volcanic ash on the ground during the volcanic eruption.

The BDCFs are calculated using the ERMYN biosphere model. BDCFs for the volcanic ash exposure scenario apply to the volcanic eruption modeling case of the igneous scenario class. The igneous scenario class is one of the TSPA disruptive scenario classes (BSC 2003 [DIRS 166296], pp. 51 to 52). The disruptive event scenario classes are developed using combinations of screened in FEPs that have a low probability of occurrence but may produce potentially adverse future conditions. The disruptive event scenario classes include the igneous scenario class, which in turn includes the igneous intrusion and volcanic eruption modeling cases, and the seismic scenario class, as well as a special case of the stylized analysis of human intrusion into the repository. The biosphere model for the volcanic ash exposure scenario, and thus the BDCFs generated using this model, support only the volcanic eruption modeling case of the disruptive event scenario classes. The remaining disruptive event scenario classes result in radionuclide releases to groundwater and are supported by the biosphere model for the groundwater scenario.

6.1 GENERAL CONSIDERATIONS

6.1.1 Radionuclides Included in the Analysis

The radionuclides of interest for the biosphere model depend on the exposure scenario, as discussed in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.1.3). The following 23 radionuclides were identified as important for the TSPA scenario classes involving radionuclide release during a volcanic eruption: strontium-90 (^{90}Sr), technetium-99 (^{99}Tc), tin-126 (^{126}Sn), cesium-137 (^{137}Cs), lead-210 (^{210}Pb), radium-226 (^{226}Ra), actinium-227 (^{227}Ac), thorium-229 (^{229}Th), thorium-230 (^{230}Th), thorium-232 (^{232}Th), protactinium-231 (^{231}Pa), uranium-232 (^{232}U), uranium-233 (^{233}U), uranium-234 (^{234}U), uranium-236 (^{236}U), uranium-238 (^{238}U), neptunium-237 (^{237}Np), plutonium-238 (^{238}Pu), plutonium-239 (^{239}Pu), plutonium-240 (^{240}Pu), plutonium-242 (^{242}Pu), americium-241 (^{241}Am), and americium-243 (^{243}Am) (BSC 2004 [DIRS 169460], Section 6.1.3). These radionuclides are referred to in this analysis as the primary radionuclides. The list includes radionuclides that are of potential importance during both the first 20,000 years and the period of up to 1,000,000 years (BSC 2003 [DIRS 166296], Section 1.3).

The biosphere model accounts for the decay products of the primary radionuclides. The short-lived decay products (half-lives less than 180 days) are considered to be in secular equilibrium with the parent radionuclide and their contributions to the BDCFs are included in the

BDCF for the long-lived radionuclide (either a primary radionuclide or its long-lived decay product). Two decay products of the primary radionuclides, ^{228}Th and ^{228}Ra, have half-lives greater than 180 days and are not automatically included in the BDCFs of the parent when the biosphere model is executed. Instead, for biosphere modeling they are treated like primary radionuclides. After their BDCFs are calculated, they are added to the BDCF of the parent primary radionuclide. In the case of ^{232}Th, its BDCF includes the contribution from ^{228}Ra, ^{228}Th, and their short-lived decay products. The BDCF for ^{232}U includes the contribution from ^{228}Th and its short-lived decay products.

6.1.2 Description of the Volcanic Ash Exposure Scenario

A detailed description of the volcanic ash exposure scenario, including the associated conceptual and mathematical models, is presented in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Sections 6.3.2 and 6.5). A brief summary of the main concepts and the modeling approach for the volcanic ash exposure scenario is presented in this section.

The general scenario (the release of radionuclides to the reference biosphere, environmental transport, and the subsequent exposure of the receptor) is shown schematically in Figure 6.1-1. The immediate source of radionuclides in the biosphere for this scenario is contaminated volcanic ash initially deposited on the ground surface following a volcanic eruption.

After radionuclides enter the biosphere, radionuclide migration through the biosphere occurs due to a number of transport processes that lead to contamination and accumulation in the environmental media (e.g., soil, air, flora, and fauna). The following environmental transport processes are explicitly included in the biosphere model for the volcanic ash exposure scenario:

- Resuspension of contaminated soil and ash
- Dry deposition of radionuclides on crop surfaces (resuspension of contaminated soil and subsequent adhesion of soil particles on crop surfaces)
- Translocation of contaminants from the site of deposition to the edible portions of crops
- Post-deposition contaminant retention by crops (including weathering processes)
- Radionuclide uptake by crops through the roots
- Radionuclide uptake by animals through consumption of contaminated feed and soil, and subsequent transfer to animal products
- Exhalation of radon from the soil.

Human exposure to radionuclides in the environment arises when people come in direct (inhalation and ingestion) or indirect (external exposure) contact with contaminated environmental media. Table 6.1-1 provides a summary of human exposure pathways included in the biosphere model, as well as environmental media and typical activities that may cause radiation exposure. Inhalation exposure arising from gaseous emissions from a volcano was not considered because gaseous radionuclides were not included among radionuclides of interest (Section 6.1.1).

Table 6.1-1. Receptor Exposure Pathways for the Volcanic Ash Exposure Scenario

Environmental Medium	Exposure Mode	Exposure Pathways	Examples of Typical Activities
Soil	Ingestion	Inadvertent soil ingestion.	Recreational activities, occupational activities, gardening, and consumption of fresh fruit and vegetables.
Soil	External	External radiation exposure.	Activities on or near contaminated soils.
Air	Inhalation	Breathing resuspended particles, and gases (^{222}Rn and progeny)	Outdoor activities, including soil-disturbing activities related to work and recreation. Domestic activities, including sleeping.
Plants	Ingestion	Consumption of locally produced crops: leafy vegetables, other vegetables, fruit, and grain.	Eating contaminated crop foodstuffs.
Animals	Ingestion	Consumption of locally produced animal products: meat, poultry, milk, and eggs.	Eating contaminated animal product foodstuffs.

Source: BSC (2004 [DIRS 169460], Table 6.3-3).

6.1.3 Consideration of Climate Change

Climate refers to the meteorological conditions that characteristically prevail in a particular region. The climate model for the Yucca Mountain region was formulated using paleoclimate and paleoenvironmental reconstructions based on microfossil records from Owens Lake, California cores and calcite isotope records from Devils Hole, Death Valley National Park, Nevada. The sequence and duration of past climate periods are identified from the records and applied to the Yucca Mountain site, which has a similar climate setting. The temperature and precipitation records of present-day meteorological stations at colder and wetter sites are selected to represent future climate states (BSC 2004 [DIRS 170002], Section 6.6.1).

For modeling of climate change in TSPA, the climate shifts in a series of step changes between three different climate states in the first 10,000 years: present-day climate, monsoon climate (about twice the precipitation of the present day climate), and glacial transition climate (colder than monsoon but similar precipitation) (BSC 2003 [DIRS 166296], p. 79). Within the TSPA model, these shifts require coordinating the coupled submodels because they must all simultaneously change to the appropriate climate state. To support the modeling of climate change in TSPA, the BDCFs must also be appropriate for the given climates. The discussion of the effect of climate change on volcanic ash exposure scenario BDCFs is presented in Section 6.2.5.

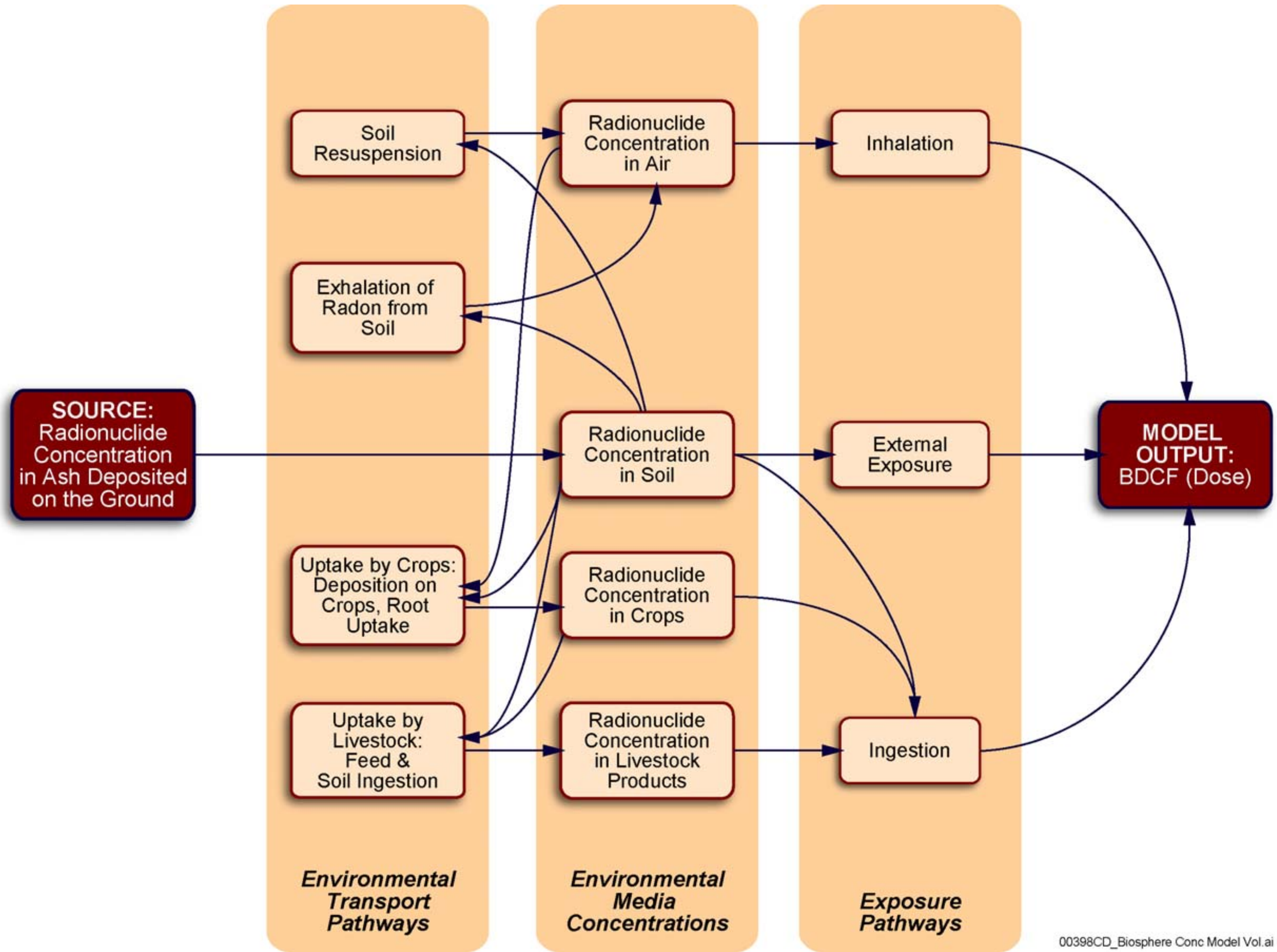


Figure 6.1-1. Conceptual Representation of the Biosphere Model for the Volcanic Ash Exposure Scenario

6.1.4 Definition of the Receptor

The regulations for licensing the repository include an individual protection standard for the performance of the repository. This standard is expressed as the annual dose limit to a hypothetical person called the reasonably maximally exposed individual (RMEI) (10 CFR 63.311 [DIRS 156605]). Analysis of annual dose includes potentially pathways of radionuclide transport and exposure (10 CFR 63.311 [DIRS 156605]). Changes in the reference biosphere, other than climate changes, are not included.

The RMEI is a hypothetical receptor that meets the following criteria (10 CFR 63.312 [DIRS 156605]):

- Lives above the highest concentration of radionuclides in the plume of contamination

- Has a diet and lifestyle representative of people who now reside in the Amargosa Valley based on surveys of the people residing in the Amargosa Valley that determine current diets and lifestyles, and then use the mean values of these factors in the assessments conducted for 10 CFR 63.311 [DIRS 156605] and 10 CFR 63.321 [DIRS 156605]

- Uses well water with average concentrations of radionuclides based on an annual water demand of 3,000 acre-feet

- Drinks 2 liters of water per day from wells drilled into the groundwater from a point above the highest concentration of radionuclides in the plume of contamination

- Is an adult who is metabolically and physiologically consistent with present knowledge of adults.

Of the above receptor characteristics those that are related to contaminated water apply only to the groundwater exposure scenario and are not used in this analysis. The evaluation of RMEI's exposure from contaminated groundwater is provided in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (see Figure 1-1).

To satisfy 10 CFR 63.312(b) [DIRS 156605] criteria, the dietary and lifestyle characteristics of the RMEI were determined based on surveys of the people living in the town of Amargosa Valley combined with national information on behavior patterns. Characteristics of the RMEI were developed in a separate analysis (BSC 2004 [DIRS 169671]).

6.1.5 Biosphere Model

This analysis was performed using a verified and validated model, ERMYN, which is described in the *Biosphere Model Report* (BSC 2004 [DIRS 169460]). The model files were obtained from the Model Warehouse (DTN: MO0306MWDBGSMF.001 [DIRS 163816]). Additional verification of the model files for GoldSim V8.01 SP4 is presented in Appendix E.

The ERMYN model was developed to model the biosphere processes for radionuclides released from the geological repository at Yucca Mountain including the environmental transport of radionuclides and human exposure. The *Biosphere Model Report* (BSC 2004 [DIRS 169460]), which describes the ERMYN model:

1. Describes the biosphere model objectives, the reference biosphere, human receptor, exposure scenarios, environmental transport pathways and human exposure pathways (BSC 2004 [DIRS 169460], Section 6.1)

2. Develops the biosphere conceptual model based on the site-specific FEPs, the reference biosphere and human receptor, and a number of assumptions (BSC 2004 [DIRS 169460], Sections 6.2 and 6.3)

3. Describes the biosphere mathematical model and its submodels based on the developed conceptual model and other published biosphere models (BSC 2004 [DIRS 169460], Sections 6.4 and 6.5)

4. Summarizes model input parameters and uncertainty distributions (BSC 2004 [DIRS 169460], Section 6.6)

5. Identifies model improvements compared with the previous biosphere model (BSC 2004 [DIRS 169460], Section 6.7)

6. Constructs the ERMYN implementation tool based on the biosphere mathematical model using GoldSim stochastic simulation software (BSC 2004 [DIRS 169460], Sections 6.8 and 6.9)

7. Verifies the ERMYN implementation tool in GoldSim (BSC 2004 [DIRS 169460], Section 6.10)

8. Validates the ERMYN model by comparing the conceptual and mathematical models and by comparing the numerical results with results from other published biosphere models (BSC 2004 [DIRS 169460], Section 7).

The ERMYN model was designed to perform an environmental radiation dose assessment and can calculate either radionuclide-specific dose or provide a radionuclide-specific BDCF for a given receptor. The use of the ERMYN model in the performance assessment is limited to calculation of BDCFs.

Input parameters for the biosphere model are developed and documented in a series of five model parameter reports:

- BSC 2004 [DIRS 169673]. *Agricultural and Environmental Parameters for the Biosphere Model*. ANL-MGR-MD-000006 REV 02.

- BSC 2004 [DIRS 169671]. *Characteristics of the Receptor for the Biosphere Model*. ANL-MGR-MD-000005 REV 03.

- BSC 2004 [DIRS 169672]. *Environmental Transport Input Parameters for the Biosphere Model*. ANL-MGR-MD-000007 REV 02.

- BSC 2004 [DIRS 169458]. *Inhalation Exposure Input Parameters for the Biosphere Model*. ANL-MGR-MD-000001 REV 03.
- BSC 2004 [DIRS 169459]. *Soil-Related Input Parameters for the Biosphere Model*. ANL-NBS-MD-000009 REV 02.

The architecture of the biosphere model for the volcanic ash exposure scenario, including the submodels, is shown in Figure 6.1-2. The submodels address radionuclide transport to, and accumulation in, specific environmental media (e.g., soil, air, plants and animals) and the inhalation, ingestion, and external exposure pathways.

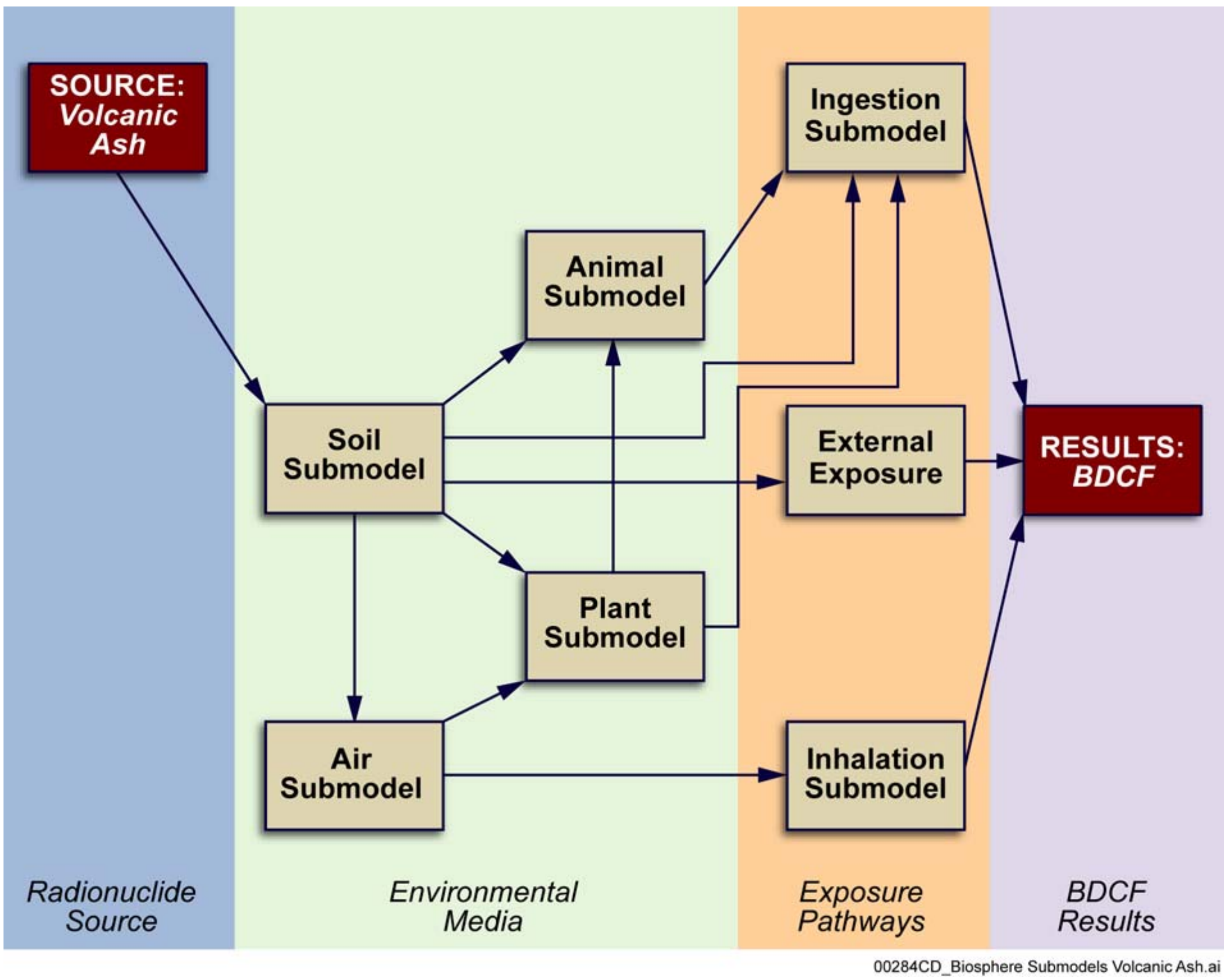


Figure 6.1-2. Relationship Between the Biosphere Submodels for the Volcanic Ash Exposure Scenario

6.2 DEVELOPMENT OF BIOSPHERE DOSE CONVERSION FACTORS FOR THE VOLCANIC ASH EXPOSURE SCENARIO

The BDCFs for the volcanic ash exposure scenario were calculated, using probabilistic analysis, in a series of simulations for each of the 23 primary radionuclides and two long-lived decay products, ^{228}Th and ^{228}Ra (see Section 6.1.1). Each simulation resulted in 1,000 model realizations. A model realization is one of the possible model outcomes obtained as a result of a single round of sampling of the model input parameters. This section describes the format and the summary of the results of biosphere modeling for the volcanic ash exposure scenario, as well as their use in the TSPA model.

6.2.1 Treatment of Uncertainty

The probabilistic approach was chosen to develop BDCFs. This approach allows statistical sampling of parameter values defined by their probability distribution functions. This method, called Monte Carlo analysis, provides a quantitative evaluation of the parameter uncertainties and their impacts on the modeling outcome. The uncertainty in the model outcome is represented by the probability distribution functions of the BDCFs. Input parameter values were sampled using Latin Hypercube sampling for consistency with the sampling technique to be used in TSPA (BSC 2003 [DIRS 166296], Section 7.3). With Latin Hypercube sampling, the probability distribution is divided into intervals of equal probability. The code then randomly samples a value within each interval, which results in a more even and consistent sampling compared with the conventional Monte Carlo random sampling scheme. The value of the random seed was set to 1.

6.2.2 Format of Biosphere Dose Conversion Factors for Volcanic Ash Exposure Scenario and Their Use in the Total System Performance Assessment Model

The radionuclide concentration in the volcanic ash deposited on the ground surface is the only source of radionuclide contamination for the volcanic ash exposure scenario used for development of BDCFs in this analysis (direct inhalation of ash during eruption phase is treated separately – see Section 6.3). Environmental transport and receptor exposure pathways discussed in the previous section depend linearly on this source.

The integration of the biosphere component into the TSPA model depends on the format of the source term, i.e., the activity concentration in the environmental medium that is the source of contamination in the biosphere. In the previous assessment, the source was expressed in terms of aerial activity concentration (activity of contaminated volcanic ash deposited per unit area of soil surface). For the source of radionuclides expressed in such a way, BDCFs for the volcanic ash exposure scenario are a function of the thickness of contaminated soil-ash surface layer. Because of the anticipated gradual decrease in airborne particulate concentration over time, the BDCFs are also a function of time. For the volcanic ash exposure scenario, the BDCFs are given in the following format (BSC 2004 [DIRS 169460], Section 6.5.8.2):

$$BDCF_i\,(d_a, t) = BDCF_{ext,ing,Rn,i} + \left(BDCF_{inh,v,i}\, f(t) + BDCF_{inh,p,i}\right) g(d_a) \qquad \text{(Eq. 6.2-1)}$$

where

$BDCF_i(d_a, t)$	=	BDCF for primary radionuclide *i* for an ash depth d_a at time *t* following a volcanic eruption (Sv/yr per Bq/m^2)
$BDCF_{ext,ing,Rn,i}$	=	BDCF for primary radionuclide *i* for external exposure, ingestion, and inhalation of radon decay products (Sv/yr per Bq/m^2)
$BDCF_{inh,v,i}$	=	BDCF for primary radionuclide *i* for short-term inhalation at post-volcanic level of mass loading in excess of nominal mass

		loading (Sv/yr per Bq/m^2)
$BDCF_{inh,p,i}$	=	BDCF for primary radionuclide *i* for long-term inhalation at nominal level of mass loading (Sv/yr per Bq/m^2)
$f(t)$	=	decay function describing reduction of mass loading with time
d_a	=	thickness of ash (m)
$g(d_a)$	=	function of ash thickness, d_a, representing the fraction of total activity that is available for resuspension.

The linearity of this equation is discussed in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.5.8.2).

Three BDCF components are calculated for each primary radionuclide. The first component, $BDCF_{ext,ing,Rn,i}$, is time independent and accounts for three exposure pathways (exposure to sources external to the body, ingestion, and inhalation of radon decay products). The second and third BDCF components account for inhaling airborne particulates. Both of these components depend on ash thickness. The second term ($BDCF_{inh,v,i}$) represents short-term inhalation exposure during the period of increased concentrations of resuspended particulates following volcanic eruption and is time-dependent because mass loading will gradually decrease after an eruption. The third term ($BDCF_{inh,p,i}$) represents long-term inhalation of resuspended particulates under nominal conditions (i.e., when the mass loading is not elevated as the result of volcanic eruption). The results of the BDCF calculations are in the format of 1,000 row vectors, one for each model realization, consisting of three BDCF components for each of the 23 primary radionuclides (i.e., 3 × 23 = 69 BDCF components per vector) and a value of critical thickness, as explained below. A vector can be regarded as a one-dimensional array containing the results of a single realization of the biosphere model for all primary radionuclides. Technically, the model is executed separately for individual primary radionuclides. The vectors are then produced by compiling the BDCFs for a given realization number. Such an approach is valid because for a given model realization number all radionuclide-independent parameters are the same regardless of a radionuclide.

The function of time, $f(t)$ in Equation 6.2-1, accounts for the reduction of mass loading in the years immediately following volcanic eruption. Mass loading decreases exponentially with time (modified from BSC 2004 [DIRS 169458], Equation 6.3-1) as

$$f(t) = e^{-\lambda t} \qquad \text{(Eq. 6.2-2)}$$

where

λ	=	mass loading decrease constant (1/yr)
t	=	time (yr); t = 0 is the first year after a volcanic eruption.

The mass loading decrease constant (Equation 6.2-2) depends on the ash thickness, and for an initial ash depth of less than 10 mm, it is represented by a triangular probability distribution function with a mode of 0.33/yr, a minimum of 0.2/yr, and a maximum of 2.0/yr

(DTN: MO0407SPAINEXI.002 [DIRS 170597]). For an initial ash depth of 10 mm or more, the mass loading decrease constant is represented by a triangular distribution with a mode of 0.20/yr, a minimum of 0.125/yr, and a maximum of 1.0/yr (DTN: MO0407SPAINEXI.002 [DIRS 170597]).

The function of ash thickness (BSC 2004 [DIRS 169460], Section 6.5.1.2), $g(d_a)$, is expressed as

$$g(d_a) = \begin{cases} 1 & \text{when } d_a < d_c \\ \dfrac{d_c}{d_a} & \text{when } d_a \geq d_c \end{cases} \qquad \text{(Eq. 6.2-3)}$$

where d_c is the critical thickness of the ash layer. The critical thickness is defined as the thickness of the surface soil (ash) layer that is available for resuspension, and the purpose of the ash thickness function is to estimate the activity concentration in this layer for the source term given as an areal activity concentration of a radionuclide. Since this parameter is represented by a distribution, the value of the critical thickness corresponding to the specific BDCF row vector must be used. The critical thickness value is thus added to each of the 1,000 BDCF row vectors.

The calculations of the all-pathway dose for any given primary radionuclide are carried out in the TSPA model by combining the source term with the BDCFs. For the volcanic ash exposure scenario, the mass loading decrease function and the ash thickness must also be factored in. The total annual dose is the sum of the annual doses from individual radionuclides tracked by the TSPA (primary radionuclides), including their decay products. The total annual dose, computed by the TSPA model, is calculated as

$$\begin{aligned} D_{total}(d_a, t) &= \sum_i BDCF_i(d_{a,} t) \times Cs_i(t) \\ &= \sum_i BDCF_{ext,ing,Rn,i} \times Cs_i(t) \qquad \text{(Eq. 6.2-4)} \\ &\quad + \sum_i \left(BDCF_{inh,v,i}\, f(t) + BDCF_{inh,p,i}\right) g(d_a) \times Cs_i(t) \end{aligned}$$

where

$D_{total}(d_a, t)$	=	time-dependent total annual dose to a defined receptor resulting from the release of radionuclides from the repository including contributions from all radionuclides considered in the TSPA-LA (Sv/yr)
$BDCF_i(d_a, t)$	=	BDCF for radionuclide i for an ash deposition depth of d_a at time t following a volcanic eruption (Sv/yr per Bq/m^2)
$Cs_i(t)$	=	time dependent activity concentration of radionuclide i in volcanic ash deposited on the ground (Bq/m^2)
$BDCF_{ext,\,ing,\,Rn,\,i}$	=	BDCF for radionuclide i for external exposure, ingestion and inhalation of radon decay products (Sv/yr per Bq/m^2)
$BDCF_{inh,v,i}$	=	BDCF for radionuclide i for inhalation of post-volcanic mass loading

in addition to nominal mass loading following a volcanic eruption (Sv/yr per Bq/m^2)

$BDCF_{inh,p,i}$ = BDCF for radionuclide *i* for inhalation of nominal mass loading following a volcanic eruption (Sv/yr per Bq/m^2)

If the radionuclide concentration in the resuspendable layer of surface soil of about 1-3 mm thickness (BSC 2004 [DIRS 169672], Section 6.8) is known, the BDCFs developed as described above can be used with the following modifications. First, for the two inhalation BDCF components, the source term, Cs_i, having the dimensions of activity per unit area can be converted to the mass activity concentration in the resuspendable layer of surface soil by using Equation 6.5.1-3 from the *Biosphere Model Report* (BSC 2004 [DIRS 169460])

$$Cs_{mc,i}(d_a) = \begin{cases} \dfrac{Cs_i}{\rho_a \times d_c} = Cs_{mc,i} & \text{when } d_a < d_c \\ \dfrac{Cs_i}{\rho_a \times d_a} = \dfrac{Cs_i}{\rho_a \times d_c}\dfrac{d_c}{d_a} = Cs_{mc,i}\dfrac{d_c}{d_a} & \text{when } d_a \geq d_c \end{cases} \quad \text{(Eq. 6.2-5)}$$

where

$Cs_{mc,i}(d_a)$ = activity concentration of radionuclide *i* in volcanic ash or in the mix of ash and dust of non-cultivated land (Bq/kg)

ρ_a = bulk density of volcanic ash (kg/m^3)

d_c = critical thickness for resuspension on non-cultivated lands (m)

d_a = thickness of ash deposited on the ground (m)

$Cs_{mc,\,i}$ = activity concentration of radionuclide *i* in the resuspendable ash or in the mix of ash and soil layer (Bq/kg)

Since in the case of known activity concentration in the resuspendable layer of soil, the soil layer under consideration can be considered equal to the critical thickness, ($d_a = d_c$), the source term, Cs_i, can simply be expressed as

$$Cs_i = Cs_{mc,i} \times (\rho_a \times d_c) \quad \text{(Eq. 6.2-6)}$$

Equation 6.2-4 thus becomes

$$\begin{aligned} D_{total}(t) &= \sum_i BDCF_{ext,ing,Rn,i} \times Cs_i(t) \\ &+ \sum_i \left(BDCF_{inh,v,i}\, f(t) + BDCF_{inh,p,i}\right)\rho_a \times d_c \times Cs_{mc,i}(t) \end{aligned} \quad \text{(Eq. 6.2-7)}$$

where the time dependence in the term $Cs_{mc,i}(t)$ denotes the time dependence of the source term.

Equations shown above use SI units for consistency with the documentation of the ERMYN model (BSC 2004 [DIRS 169460]). However, any units can be used to define parameters in GoldSim, where the ERMYN model is implemented, as long as they are dimensionally consistent. In the previous assessments, the output of the BDCF calculations was presented in units of rem/yr or mrem/yr per pCi/m^2, and this analysis follows the same format.

6.2.3 Results of the Calculations

The outcome of the volcanic ash exposure scenario BDCF calculations consists of the three BDCF components generated for each radionuclide and each model realization (3 radionuclide-dependent BDCF components × 1,000 realizations per radionuclide × (23 + 2) radionuclides = 75,000 data points). A summary of these results, in the form of discrete cumulative probability distributions of BDCFs in 5 percentile increments, plus means and standard deviations, is presented in Tables 6.2-1 to 6.2-3 for the external-ingestion-radon component, short-term inhalation component, and the long-term inhalation component, respectively. The list of biosphere model files is provided in Appendix A. The means, standard deviations, and percentiles were calculated in an Excel spreadsheet *VA BDCF Realizations MC_Rev 3.xls*, which is described in Appendix B.

In all tables presenting the results of BDCF calculations, BDCFs for ^{232}Th include contributions from ^{228}Ra and ^{228}Th; BDCFs for ^{232}U include the contribution from ^{228}Th.

Table 6.2-1. BDCF Component for External Exposure, Ingestion, and Inhalation of Radon Decay Products (rem/yr per pCi/m^2)

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	2.11E-09	6.44E-10	9.38E-08	2.68E-08	7.12E-09	1.61E-07	2.38E-08	1.66E-08	2.30E-10	1.14E-07	6.91E-09	6.88E-08
STD	1.74E-09	2.04E-09	1.78E-09	6.07E-10	1.19E-08	1.01E-08	5.28E-09	1.50E-09	2.03E-10	2.90E-09	6.09E-09	2.02E-09
Min.	4.10E-10	1.73E-11	8.79E-08	2.52E-08	6.88E-10	1.41E-07	1.87E-08	1.48E-08	5.66E-11	1.07E-07	2.44E-09	6.46E-08
5%	6.45E-10	4.66E-11	9.12E-08	2.59E-08	1.39E-09	1.45E-07	1.97E-08	1.54E-08	7.76E-11	1.10E-07	2.93E-09	6.63E-08
10%	7.63E-10	6.44E-11	9.18E-08	2.61E-08	1.69E-09	1.48E-07	2.00E-08	1.55E-08	8.79E-11	1.11E-07	3.15E-09	6.68E-08
15%	8.66E-10	8.67E-11	9.22E-08	2.62E-08	1.91E-09	1.50E-07	2.03E-08	1.56E-08	9.75E-11	1.11E-07	3.34E-09	6.71E-08
20%	9.40E-10	1.05E-10	9.25E-08	2.63E-08	2.20E-09	1.52E-07	2.05E-08	1.57E-08	1.05E-10	1.12E-07	3.59E-09	6.73E-08
25%	1.03E-09	1.30E-10	9.27E-08	2.64E-08	2.46E-09	1.53E-07	2.08E-08	1.58E-08	1.15E-10	1.12E-07	3.78E-09	6.75E-08
30%	1.14E-09	1.49E-10	9.29E-08	2.65E-08	2.77E-09	1.55E-07	2.10E-08	1.59E-08	1.22E-10	1.12E-07	3.97E-09	6.77E-08
35%	1.22E-09	1.76E-10	9.32E-08	2.65E-08	3.04E-09	1.56E-07	2.12E-08	1.60E-08	1.31E-10	1.13E-07	4.21E-09	6.80E-08
40%	1.32E-09	2.10E-10	9.34E-08	2.66E-08	3.41E-09	1.58E-07	2.15E-08	1.60E-08	1.43E-10	1.13E-07	4.49E-09	6.82E-08
45%	1.44E-09	2.49E-10	9.36E-08	2.67E-08	3.95E-09	1.60E-07	2.18E-08	1.61E-08	1.53E-10	1.13E-07	4.74E-09	6.84E-08
50%	1.56E-09	2.96E-10	9.38E-08	2.67E-08	4.31E-09	1.61E-07	2.21E-08	1.62E-08	1.67E-10	1.13E-07	4.98E-09	6.85E-08
55%	1.69E-09	3.46E-10	9.40E-08	2.68E-08	4.77E-09	1.63E-07	2.25E-08	1.63E-08	1.81E-10	1.14E-07	5.34E-09	6.86E-08
60%	1.84E-09	4.10E-10	9.42E-08	2.68E-08	5.35E-09	1.64E-07	2.29E-08	1.64E-08	1.95E-10	1.14E-07	5.78E-09	6.88E-08
65%	2.04E-09	4.80E-10	9.44E-08	2.69E-08	5.93E-09	1.66E-07	2.33E-08	1.66E-08	2.13E-10	1.14E-07	6.25E-09	6.91E-08
70%	2.31E-09	5.56E-10	9.45E-08	2.70E-08	6.73E-09	1.68E-07	2.39E-08	1.67E-08	2.35E-10	1.15E-07	6.97E-09	6.93E-08
75%	2.58E-09	7.00E-10	9.48E-08	2.70E-08	7.80E-09	1.70E-07	2.45E-08	1.69E-08	2.58E-10	1.15E-07	7.72E-09	6.96E-08
80%	2.92E-09	8.56E-10	9.51E-08	2.71E-08	9.03E-09	1.71E-07	2.55E-08	1.72E-08	3.05E-10	1.15E-07	8.78E-09	6.99E-08
85%	3.42E-09	1.05E-09	9.53E-08	2.72E-08	1.07E-08	1.73E-07	2.70E-08	1.76E-08	3.61E-10	1.16E-07	1.01E-08	7.04E-08
90%	4.09E-09	1.33E-09	9.57E-08	2.74E-08	1.39E-08	1.75E-07	2.95E-08	1.83E-08	4.53E-10	1.17E-07	1.18E-08	7.08E-08
95%	5.39E-09	1.97E-09	9.63E-08	2.76E-08	1.91E-08	1.77E-07	3.28E-08	1.93E-08	5.85E-10	1.18E-07	1.72E-08	7.17E-08
Max.	2.11E-08	5.87E-08	1.18E-07	3.25E-08	2.40E-07	1.90E-07	7.83E-08	3.14E-08	2.24E-09	1.40E-07	7.17E-08	9.17E-08

Table 6.2-1. BDCF Component for External Exposure, Ingestion, and Inhalation of Radon Decay Products, rem/yr per pCi/m^2 (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	3.54E-10	3.36E-10	3.11E-10	1.74E-09	2.11E-08	1.06E-09	1.17E-09	1.17E-09	1.11E-09	2.01E-09	1.15E-08
STD	3.46E-10	3.39E-10	3.22E-10	3.21E-10	2.20E-08	1.09E-09	1.20E-09	1.20E-09	1.14E-09	1.25E-09	1.25E-09
Min.	7.42E-11	6.03E-11	4.92E-11	1.45E-09	1.07E-08	1.58E-10	1.70E-10	1.72E-10	1.62E-10	9.53E-10	1.02E-08
5%	1.11E-10	9.72E-11	8.44E-11	1.51E-09	1.14E-08	2.71E-10	2.96E-10	2.97E-10	2.81E-10	1.10E-09	1.05E-08
10%	1.27E-10	1.13E-10	9.89E-11	1.53E-09	1.17E-08	3.27E-10	3.57E-10	3.59E-10	3.39E-10	1.16E-09	1.06E-08
15%	1.43E-10	1.28E-10	1.14E-10	1.54E-09	1.19E-08	3.68E-10	4.02E-10	4.04E-10	3.82E-10	1.21E-09	1.07E-08
20%	1.55E-10	1.40E-10	1.25E-10	1.55E-09	1.21E-08	4.17E-10	4.57E-10	4.59E-10	4.34E-10	1.26E-09	1.08E-08
25%	1.67E-10	1.51E-10	1.36E-10	1.57E-09	1.24E-08	4.64E-10	5.08E-10	5.10E-10	4.83E-10	1.32E-09	1.08E-08
30%	1.81E-10	1.66E-10	1.49E-10	1.58E-09	1.26E-08	5.10E-10	5.60E-10	5.61E-10	5.31E-10	1.37E-09	1.09E-08
35%	1.97E-10	1.81E-10	1.64E-10	1.59E-09	1.29E-08	5.52E-10	6.06E-10	6.08E-10	5.76E-10	1.42E-09	1.10E-08
40%	2.12E-10	1.96E-10	1.78E-10	1.61E-09	1.32E-08	6.07E-10	6.67E-10	6.68E-10	6.33E-10	1.48E-09	1.10E-08
45%	2.30E-10	2.14E-10	1.95E-10	1.62E-09	1.37E-08	6.56E-10	7.20E-10	7.22E-10	6.84E-10	1.55E-09	1.11E-08
50%	2.53E-10	2.36E-10	2.16E-10	1.64E-09	1.42E-08	7.21E-10	7.92E-10	7.94E-10	7.52E-10	1.62E-09	1.12E-08
55%	2.72E-10	2.55E-10	2.34E-10	1.67E-09	1.49E-08	7.99E-10	8.79E-10	8.80E-10	8.34E-10	1.71E-09	1.12E-08
60%	2.95E-10	2.78E-10	2.55E-10	1.69E-09	1.57E-08	8.57E-10	9.43E-10	9.44E-10	8.95E-10	1.79E-09	1.14E-08
65%	3.28E-10	3.10E-10	2.86E-10	1.72E-09	1.67E-08	9.64E-10	1.06E-09	1.06E-09	1.01E-09	1.92E-09	1.15E-08
70%	3.65E-10	3.46E-10	3.21E-10	1.75E-09	1.80E-08	1.08E-09	1.19E-09	1.19E-09	1.13E-09	2.04E-09	1.16E-08
75%	4.16E-10	3.95E-10	3.67E-10	1.79E-09	1.97E-08	1.21E-09	1.33E-09	1.33E-09	1.27E-09	2.20E-09	1.17E-08
80%	4.73E-10	4.52E-10	4.21E-10	1.85E-09	2.25E-08	1.44E-09	1.58E-09	1.58E-09	1.50E-09	2.44E-09	1.19E-08
85%	5.60E-10	5.37E-10	5.01E-10	1.94E-09	2.66E-08	1.70E-09	1.87E-09	1.87E-09	1.78E-09	2.79E-09	1.23E-08
90%	6.93E-10	6.68E-10	6.26E-10	2.04E-09	3.37E-08	2.23E-09	2.46E-09	2.46E-09	2.34E-09	3.34E-09	1.29E-08
95%	9.05E-10	8.76E-10	8.23E-10	2.24E-09	6.01E-08	2.89E-09	3.19E-09	3.19E-09	3.03E-09	4.12E-09	1.36E-08
Max.	5.02E-09	4.92E-09	4.65E-09	6.07E-09	4.06E-07	1.29E-08	1.42E-08	1.42E-08	1.35E-08	1.54E-08	2.49E-08

Sources: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150], MO0306MWDBGSMF.001 [DIRS 163816].

NOTE: Calculated in Excel file *VA BDCF Realizations MC_Rev 3.xls* as shown in Appendix B.

Table 6.2-2. BDCF Component for Short-Term Inhalation Exposure, rem/yr per pCi/m^2

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	5.32E-10	1.79E-11	2.17E-10	6.85E-11	4.97E-08	1.85E-08	1.44E-05	4.65E-06	6.99E-07	4.27E-06	2.76E-06	2.15E-06
STD	3.36E-10	1.13E-11	1.37E-10	4.33E-11	3.15E-08	1.17E-08	9.12E-06	2.94E-06	4.42E-07	2.70E-06	1.74E-06	1.36E-06
Min.	4.08E-11	1.37E-12	1.67E-11	5.26E-12	3.82E-09	1.42E-09	1.11E-06	3.57E-07	5.36E-08	3.28E-07	2.12E-07	1.65E-07
5%	1.43E-10	4.80E-12	5.83E-11	1.84E-11	1.34E-08	4.96E-09	3.87E-06	1.25E-06	1.88E-07	1.15E-06	7.40E-07	5.78E-07
10%	1.92E-10	6.45E-12	7.84E-11	2.47E-11	1.79E-08	6.66E-09	5.2E-06	1.68E-06	2.52E-07	1.54E-06	9.94E-07	7.77E-07
15%	2.31E-10	7.76E-12	9.43E-11	2.98E-11	2.16E-08	8.02E-09	6.27E-06	2.02E-06	3.04E-07	1.85E-06	1.20E-06	9.35E-07
20%	2.65E-10	8.91E-12	1.08E-10	3.42E-11	2.48E-08	9.20E-09	7.19E-06	2.32E-06	3.49E-07	2.13E-06	1.37E-06	1.07E-06
25%	2.94E-10	9.88E-12	1.20E-10	3.79E-11	2.75E-08	1.02E-08	7.97E-06	2.57E-06	3.86E-07	2.36E-06	1.52E-06	1.19E-06
30%	3.24E-10	1.09E-11	1.32E-10	4.18E-11	3.03E-08	1.12E-08	8.79E-06	2.83E-06	4.26E-07	2.6E-06	1.68E-06	1.31E-06
35%	3.52E-10	1.18E-11	1.44E-10	4.54E-11	3.29E-08	1.22E-08	9.55E-06	3.07E-06	4.62E-07	2.82E-06	1.82E-06	1.43E-06
40%	3.86E-10	1.30E-11	1.58E-10	4.97E-11	3.61E-08	1.34E-08	1.05E-05	3.37E-06	5.07E-07	3.1E-06	2.00E-06	1.56E-06
45%	4.22E-10	1.42E-11	1.72E-10	5.43E-11	3.94E-08	1.46E-08	1.14E-05	3.68E-06	5.54E-07	3.38E-06	2.18E-06	1.71E-06
50%	4.54E-10	1.52E-11	1.85E-10	5.84E-11	4.24E-08	1.57E-08	1.23E-05	3.96E-06	5.96E-07	3.64E-06	2.35E-06	1.84E-06
55%	4.84E-10	1.63E-11	1.98E-10	6.24E-11	4.53E-08	1.68E-08	1.31E-05	4.23E-06	6.36E-07	3.89E-06	2.51E-06	1.96E-06
60%	5.36E-10	1.80E-11	2.19E-10	6.90E-11	5.01E-08	1.86E-08	1.45E-05	4.68E-06	7.04E-07	4.30E-06	2.77E-06	2.17E-06
65%	5.77E-10	1.94E-11	2.36E-10	7.43E-11	5.39E-08	2.00E-08	1.56E-05	5.04E-06	7.58E-07	4.63E-06	2.99E-06	2.34E-06
70%	6.26E-10	2.10E-11	2.56E-10	8.07E-11	5.86E-08	2.17E-08	1.70E-05	5.47E-06	8.23E-07	5.03E-06	3.24E-06	2.54E-06
75%	6.89E-10	2.31E-11	2.81E-10	8.87E-11	6.44E-08	2.39E-08	1.87E-05	6.02E-06	9.05E-07	5.53E-06	3.57E-06	2.79E-06
80%	7.56E-10	2.54E-11	3.09E-10	9.74E-11	7.07E-08	2.62E-08	2.05E-05	6.60E-06	9.93E-07	6.07E-06	3.92E-06	3.06E-06
85%	8.38E-10	2.81E-11	3.42E-10	1.08E-10	7.83E-08	2.91E-08	2.27E-05	7.32E-06	1.10E-06	6.72E-06	4.34E-06	3.39E-06
90%	9.54E-10	3.02E-11	3.90E-10	1.23E-10	8.92E-08	3.31E-08	2.59E-05	8.33E-06	1.25E-06	7.66E-06	4.94E-06	3.86E-06
95%	1.20E-09	4.02E-11	4.88E-10	1.54E-10	1.12E-07	4.15E-08	3.24E-05	1.04E-05	1.57E-06	9.6E-06	6.2E-06	4.84E-06
Max.	2.39E-09	8.02E-11	9.75E-10	3.08E-10	2.23E-07	8.29E-08	6.48E-05	2.09E-05	3.14E-06	1.92E-05	1.24E-05	9.67E-06

Table 6.2-2. BDCF Component for Short-Term Inhalation Exposure, rem/yr per pCi/m^2 (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	2.91E-07	2.84E-07	2.69E-07	2.54E-07	1.16E-06	8.42E-07	9.21E-07	9.21E-07	8.81E-07	9.53E-07	9.45E-07
STD	1.84E-07	1.80E-07	1.70E-07	1.61E-07	7.33E-07	5.32E-07	5.83E-07	5.83E-07	5.58E-07	6.03E-07	5.98E-07
Min.	2.23E-08	2.18E-08	2.07E-08	1.95E-08	8.90E-08	6.46E-08	7.07E-08	7.07E-08	6.77E-08	7.31E-08	7.25E-08
5%	7.81E-08	7.64E-08	7.23E-08	6.83E-08	3.11E-07	2.26E-07	2.47E-07	2.47E-07	2.37E-07	2.56E-07	2.54E-07
10%	1.05E-07	1.03E-07	9.71E-08	9.17E-08	4.18E-07	3.04E-07	3.32E-07	3.32E-07	3.18E-07	3.44E-07	3.41E-07
15%	1.26E-07	1.23E-07	1.17E-07	1.10E-07	5.04E-07	3.66E-07	4.00E-07	4.00E-07	3.83E-07	4.14E-07	4.10E-07
20%	1.45E-07	1.42E-07	1.34E-07	1.27E-07	5.78E-07	4.20E-07	4.59E-07	4.59E-07	4.40E-07	4.75E-07	4.71E-07
25%	1.61E-07	1.57E-07	1.49E-07	1.41E-07	6.41E-07	4.65E-07	5.09E-07	5.09E-07	4.87E-07	5.27E-07	5.22E-07
30%	1.77E-07	1.73E-07	1.64E-07	1.55E-07	7.07E-07	5.13E-07	5.61E-07	5.61E-07	5.37E-07	5.81E-07	5.76E-07
35%	1.92E-07	1.88E-07	1.78E-07	1.68E-07	7.67E-07	5.57E-07	6.10E-07	6.10E-07	5.83E-07	6.31E-07	6.25E-07
40%	2.11E-07	2.06E-07	1.95E-07	1.84E-07	8.41E-07	6.11E-07	6.68E-07	6.68E-07	6.40E-07	6.91E-07	6.86E-07
45%	2.30E-07	2.25E-07	2.13E-07	2.01E-07	9.19E-07	6.67E-07	7.30E-07	7.30E-07	6.99E-07	7.55E-07	7.49E-07
50%	2.48E-07	2.42E-07	2.30E-07	2.17E-07	9.89E-07	7.18E-07	7.86E-07	7.86E-07	7.52E-07	8.13E-07	8.06E-07
55%	2.65E-07	2.59E-07	2.45E-07	2.31E-07	1.06E-06	7.66E-07	8.38E-07	8.38E-07	8.02E-07	8.67E-07	8.60E-07
60%	2.93E-07	2.86E-07	2.71E-07	2.56E-07	1.17E-06	8.48E-07	9.28E-07	9.28E-07	8.88E-07	9.06E-07	9.52E-07
65%	3.15E-07	3.08E-07	2.92E-07	2.76E-07	1.26E-06	9.13E-07	9.99E-07	9.99E-07	9.56E-07	1.03E-06	1.02E-06
70%	3.42E-07	3.35E-07	3.17E-07	2.99E-07	1.37E-06	9.91E-07	1.08E-06	1.08E-06	1.04E-06	1.12E-06	1.11E-06
75%	3.76E-07	3.68E-07	3.49E-07	3.29E-07	1.50E-06	1.09E-06	1.19E-06	1.19E-06	1.14E-06	1.23E-06	1.22E-06
80%	4.13E-07	4.04E-07	3.83E-07	3.61E-07	1.65E-06	1.20E-06	1.31E-06	1.31E-06	1.25E-06	1.35E-06	1.34E-06
85%	4.58E-07	4.48E-07	4.24E-07	4.00E-07	1.83E-06	1.33E-06	1.45E-06	1.45E-06	1.39E-06	1.5E-06	1.49E-06
90%	5.21E-07	5.10E-07	4.83E-07	4.56E-07	2.08E-06	1.51E-06	1.65E-06	1.65E-06	1.58E-06	1.71E-06	1.69E-06
95%	6.54E-07	6.39E-07	6.05E-07	5.72E-07	2.61E-06	1.89E-06	2.07E-06	2.07E-06	1.98E-06	2.14E-06	2.13E-06
Max.	1.30E-06	1.28E-06	1.21E-06	1.14E-06	5.21E-06	3.78E-06	4.14E-06	4.14E-06	3.96E-06	4.28E-06	4.24E-06

Sources: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150], MO0306MWDBGSMF.001 [DIRS 163816].

NOTE: Calculated in Excel file *VA BDCF Realizations MC_Rev 3.xls* as shown in Appendix B.

Table 6.2-3. BDCF Component for Long-Term Inhalation Exposure, rem/yr per pCi/m^2

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	1.06E-09	3.56E-11	4.33E-10	1.37E-10	9.92E-08	3.68E-08	2.88E-05	9.27E-06	1.39E-06	8.52E-06	5.50E-06	4.30E-06
STD	6.27E-10	2.11E-11	2.56E-10	8.08E-11	5.87E-08	2.18E-08	1.70E-05	5.48E-06	8.24E-07	5.03E-06	3.25E-06	2.54E-06
Min.	1.44E-10	4.82E-12	5.87E-11	1.85E-11	1.34E-08	4.98E-09	3.90E-06	1.25E-06	1.89E-07	1.15E-06	7.44E-07	5.82E-07
5%	3.37E-10	1.13E-11	1.38E-10	4.35E-11	3.15E-08	1.17E-08	9.15E-06	2.95E-06	4.43E-07	2.71E-06	1.75E-06	1.37E-06
10%	4.24E-10	1.42E-11	1.73E-10	5.46E-11	3.96E-08	1.47E-08	1.15E-05	3.70E-06	5.57E-07	3.40E-06	2.20E-06	1.72E-06
15%	4.77E-10	1.60E-11	1.95E-10	6.15E-11	4.46E-08	1.66E-08	1.29E-05	4.17E-06	6.27E-07	3.83E-06	2.47E-06	1.93E-06
20%	5.49E-10	1.85E-11	2.24E-10	7.08E-11	5.14E-08	1.91E-08	1.49E-05	4.80E-06	7.22E-07	4.41E-06	2.85E-06	2.22E-06
25%	6.05E-10	2.03E-11	2.47E-10	7.79E-11	5.65E-08	2.10E-08	1.64E-05	5.28E-06	7.95E-07	4.85E-06	3.13E-06	2.45E-06
30%	6.53E-10	2.19E-11	2.67E-10	8.41E-11	6.10E-08	2.26E-08	1.77E-05	5.70E-06	8.58E-07	5.24E-06	3.38E-06	2.64E-06
35%	6.99E-10	2.35E-11	2.86E-10	9.01E-11	6.54E-08	2.43E-08	1.90E-05	6.11E-06	9.19E-07	5.61E-06	3.62E-06	2.83E-06
40%	7.79E-10	2.62E-11	3.18E-10	1.00E-10	7.29E-08	2.70E-08	2.11E-05	6.81E-06	1.02E-06	6.25E-06	4.04E-06	3.15E-06
45%	8.39E-10	2.82E-11	3.43E-10	1.08E-10	7.85E-08	2.91E-08	2.28E-05	7.33E-06	1.10E-06	6.74E-06	4.35E-06	3.40E-06
50%	9.09E-10	3.05E-11	3.71E-10	1.17E-10	8.50E-08	3.15E-08	2.47E-05	7.94E-06	1.19E-06	7.30E-06	4.71E-06	3.68E-06
55%	9.99E-10	3.36E-11	4.08E-10	1.29E-10	9.34E-08	3.47E-08	2.71E-05	8.73E-06	1.31E-06	8.02E-06	5.18E-06	4.05E-06
60%	1.08E-09	3.64E-11	4.43E-10	1.4E-10	1.01E-07	3.76E-08	2.94E-05	9.47E-06	1.42E-06	8.70E-06	5.62E-06	4.39E-06
65%	1.18E-09	3.95E-11	4.80E-10	1.51E-10	1.10E-07	4.08E-08	3.19E-05	1.03E-05	1.54E-06	9.44E-06	6.09E-06	4.76E-06
70%	1.26E-09	4.24E-11	5.16E-10	1.63E-10	1.18E-07	4.38E-08	3.42E-05	1.10E-05	1.66E-06	1.01E-05	6.54E-06	5.11E-06
75%	1.37E-09	4.61E-11	5.61E-10	1.77E-10	1.28E-07	4.76E-08	3.72E-05	1.20E-05	1.80E-06	1.10E-05	7.11E-06	5.56E-06
80%	1.54E-09	5.16E-11	6.27E-10	1.98E-10	1.44E-07	5.33E-08	4.16E-05	1.34E-05	2.02E-06	1.23E-05	7.95E-06	6.22E-06
85%	1.66E-09	5.57E-11	6.78E-10	2.14E-10	1.55E-07	5.76E-08	4.5E-05	1.45E-05	2.18E-06	1.33E-05	8.60E-06	6.72E-06
90%	1.86E-09	6.24E-11	7.59E-10	2.39E-10	1.74E-07	6.45E-08	5.04E-05	1.62E-05	2.44E-06	1.49E-05	9.63E-06	7.53E-06
95%	2.26E-09	7.59E-11	9.23E-10	2.91E-10	2.11E-07	7.84E-08	6.13E-05	1.97E-05	2.97E-06	1.81E-05	1.17E-05	9.15E-06
Max.	4.92E-09	1.65E-10	2.01E-09	6.34E-10	4.6E-07	1.71E-07	1.34E-04	4.3E-05	6.47E-06	3.95E-05	2.55E-05	1.99E-05

Table 6.2-3. BDCF Component for Long-Term Inhalation Exposure, rem/yr per pCi/m^2 (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	5.80E-07	5.67E-07	5.37E-07	5.07E-07	2.31E-06	1.68E-06	1.84E-06	1.84E-06	1.76E-06	1.90E-06	1.89E-06
STD	3.43E-07	3.35E-07	3.17E-07	3.00E-07	1.37E-06	9.93E-07	1.09E-06	1.09E-06	1.04E-06	1.12E-06	1.11E-06
Min.	7.85E-08	7.68E-08	7.27E-08	6.86E-08	3.13E-07	2.27E-07	2.49E-07	2.49E-07	2.38E-07	2.57E-07	2.55E-07
5%	1.84E-07	1.80E-07	1.71E-07	1.61E-07	7.35E-07	5.34E-07	5.84E-07	5.84E-07	5.59E-07	6.04E-07	5.99E-07
10%	2.32E-07	2.27E-07	2.15E-07	2.03E-07	9.24E-07	6.71E-07	7.34E-07	7.34E-07	7.03E-07	7.59E-07	7.53E-07
15%	2.61E-07	2.55E-07	2.42E-07	2.28E-07	1.04E-06	7.55E-07	8.27E-07	8.27E-07	7.91E-07	8.55E-07	8.48E-07
20%	3.00E-07	2.94E-07	2.78E-07	2.63E-07	1.20E-06	8.69E-07	9.51E-07	9.51E-07	9.1E-07	9.84E-07	9.76E-07
25%	3.3E-07	3.23E-07	3.06E-07	2.89E-07	1.32E-06	9.57E-07	1.05E-06	1.05E-06	1.00E-06	1.08E-06	1.07E-06
30%	3.57E-07	3.49E-07	3.30E-07	3.12E-07	1.42E-06	1.03E-06	1.13E-06	1.13E-06	1.08E-06	1.17E-06	1.16E-06
35%	3.82E-07	3.74E-07	3.54E-07	3.34E-07	1.52E-06	1.11E-06	1.21E-06	1.21E-06	1.16E-06	1.25E-06	1.24E-06
40%	4.26E-07	4.16E-07	3.94E-07	3.72E-07	1.70E-06	1.23E-06	1.35E-06	1.35E-06	1.29E-06	1.40E-06	1.38E-06
45%	4.59E-07	4.49E-07	4.25E-07	4.01E-07	1.83E-06	1.33E-06	1.45E-06	1.45E-06	1.39E-06	1.50E-06	1.49E-06
50%	4.97E-07	4.86E-07	4.60E-07	4.35E-07	1.98E-06	1.44E-06	1.57E-06	1.57E-06	1.51E-06	1.63E-06	1.62E-06
55%	5.46E-07	5.34E-07	5.06E-07	4.77E-07	2.18E-06	1.58E-06	1.73E-06	1.73E-06	1.66E-06	1.79E-06	1.77E-06
60%	5.92E-07	5.8E-07	5.49E-07	5.18E-07	2.36E-06	1.72E-06	1.88E-06	1.88E-06	1.80E-06	1.94E-06	1.93E-06
65%	6.43E-07	6.28E-07	5.95E-07	5.62E-07	2.56E-06	1.86E-06	2.04E-06	2.04E-06	1.95E-06	2.11E-06	2.09E-06
70%	6.90E-07	6.75E-07	6.39E-07	6.04E-07	2.75E-06	2.00E-06	2.19E-06	2.19E-06	2.09E-06	2.26E-06	2.24E-06
75%	7.50E-07	7.34E-07	6.95E-07	6.56E-07	2.99E-06	2.17E-06	2.38E-06	2.38E-06	2.28E-06	2.46E-06	2.44E-06
80%	8.39E-07	8.21E-07	7.77E-07	7.34E-07	3.35E-06	2.43E-06	2.66E-06	2.66E-06	2.54E-06	2.75E-06	2.73E-06
85%	9.07E-07	8.87E-07	8.40E-07	7.93E-07	3.62E-06	2.63E-06	2.87E-06	2.87E-06	2.75E-06	2.97E-06	2.95E-06
90%	1.02E-06	9.93E-07	9.41E-07	8.88E-07	4.05E-06	2.94E-06	3.22E-06	3.22E-06	3.08E-06	3.33E-06	3.30E-06
95%	1.24E-06	1.21E-06	1.14E-06	1.08E-06	4.93E-06	3.58E-06	3.91E-06	3.91E-06	3.75E-06	4.05E-06	4.02E-06
Max.	2.69E-06	2.63E-06	2.49E-06	2.35E-06	1.07E-05	7.79E-06	8.53E-06	8.53E-06	8.16E-06	8.82E-06	8.75E-06

Sources: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150]. MO0306MWDBGSMF.001 [DIRS 163816].

NOTE: Calculated in Excel file *VA BDCF Realizations MC_Rev 3.xls* as shown in Appendix B.

Correlations among input values for the radionuclides have been appropriately established. In general, The BDCFs for the volcanic ash scenario can be correlated because most of the input parameters, especially those that are radionuclide-independent, are the same for different radionuclides. Correlations exist between the BDCF components for a given radionuclide and between the BDCFs for individual radionuclides. The rank correlation coefficients for the BDCF components are listed in Table 6.2-4. There is no correlation or a very poor correlation between the external/ingestion/radon BDCF component and any of the inhalation components because these components are related to different exposure pathways and thus depend on a different set of input parameters. A stronger correlation exists only between the inhalation BDCF components, the long-term and the short-term, because they depend on the same set of parameters describing behavior of the receptor and the receptor environments.

Table 6.2-4. Rank Correlation Coefficients for the Volcanic Ash Scenario BDCF Components

Radionuclide	External-Ingestion-Radon and Short-term Inhalation	Short-term Inhalation and Long-term Inhalation	External-Ingestion-Radon and Long-term Inhalation
^{90}Sr	0	0.583	0
^{99}Tc	0	0.583	0
^{126}Sn	0.129	0.583	0.169
^{137}Cs	0.105	0.583	0.145
^{210}Pb	0	0.583	0
^{226}Ra	0	0.583	0
^{227}Ac	0	0.583	0
^{229}Th	0	0.583	0
^{230}Th	0	0.583	0
^{232}Th	0	0.583	0.115
^{231}Pa	0	0.583	0
^{232}U	0	0.583	0.106
^{233}U	0	0.583	0
^{234}U	0	0.583	0
^{236}U	0	0.583	0
^{238}U	0	0.583	0
^{237}Np	0	0.583	0
^{238}Pu	0	0.583	0
^{239}Pu	0	0.583	0
^{240}Pu	0	0.583	0
^{242}Pu	0	0.583	0
^{241}Am	0	0.583	0

Sources: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150], MO0306MWDBGSMF.001 [DIRS 163816].

NOTE: Calculated in Excel file *VA BDCF MC Correlations_Rev 3.xls* as shown in Appendix B.

The rank correlations between the BDCF components of different radionuclides have also been calculated. The correlation coefficients for the external-ingestion-radon component are listed in Table 6.2-5. Correlation coefficients for short-term and long-term inhalation components are equal to 1. Details of the calculations are presented in Appendix B. Generally, the correlation coefficients for the external exposure-radon-ingestion BDCF components are the highest for actinides (^{227}Ac and heavier radionuclides) and relatively low for lighter radionuclides. This depends on the importance of individual pathways, and input parameters for these pathways, for this BDCF component.

Some correlation coefficients in Tables 6.2-4 and 6.2-5 are shown as equal to zero. This absence of correlation between the variables was determined by performing a statistical test on the calculated value of the correlation coefficient. The hypothesis was that the (true) population correlation coefficient is equal to zero. If the calculated value of the correlation coefficient for the sampling distribution is equal to *r*, one can compute the values of a parameter *t*, such that

$$t = \frac{r}{\sqrt{\frac{(1-r^2)}{n-2}}} \qquad \text{(Eq. 6.2-8)}$$

where *n* is the number of data points in the sampling distribution, and compare its value with Student's *t* for *n-2* degrees of freedom (Steel and Torrie 1980 [DIRS 150857], pp. 278 to 279). Table 6.2-6 lists the values of *t* calculated from Equation 6.2-8 for different values of *r*. The hypothesis that the population correlation coefficient is equal to zero (no correlation) can be rejected at the 99% confidence level if the value of *t* is less than 2.576 (Lide and Frederikse 1997 [DIRS 103178], p. A-105). (The one-tail area under the probability distribution function for variable *t* is equal to 0.995 for $t = 2.576$.) This corresponds to the value of *r* equal to 0.0813. Note that the distribution of *t* approaches a normal distribution for the large number of degrees of freedom, which is the case here. The correlation coefficient was thus set to zero for the calculated values less than 0.0813.

Table 6.2-5. Rank Correlations (Correlation Coefficients) Among the External Exposure-Ingestion-Radon BDCF Components for Individual Radionuclides

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
^{90}Sr	1.000											
^{99}Tc	0.269	1.000										
^{126}Sn	0	0	1.000									
^{137}Cs	0.148	0.094	0.811	1.000								
^{210}Pb	0.388	0.228	0	0.187	1.000							
^{226}Ra	0	0	0.243	0.237	0	1.000						
^{227}Ac	0.407	0.254	0.109	0.306	0.626	0.118	1.000					
^{229}Th	0.383	0.247	0.277	0.442	0.608	0.157	0.913	1.000				
^{230}Th	0.403	0.266	0	0.196	0.637	0.082	0.925	0.934	1.000			
^{232}Th	0.251	0.166	0.715	0.767	0.388	0.262	0.591	0.735	0.515	1.000		
^{231}Pa	0.369	0.261	0	0.212	0.580	0	0.807	0.778	0.811	0.477	1.000	
^{232}U	0.274	0.161	0.661	0.697	0.399	0.244	0.574	0.697	0.487	0.849	0.455	1.000
^{233}U	0.382	0.275	0	0.160	0.532	0	0.669	0.640	0.670	0.394	0.562	0.648
^{234}U	0.382	0.275	0	0.160	0.532	0	0.669	0.640	0.670	0.394	0.562	0.648
^{236}U	0.382	0.275	0	0.160	0.532	0	0.669	0.640	0.670	0.393	0.562	0.647
^{238}U	0.378	0.266	0.152	0.295	0.524	0.122	0.680	0.686	0.656	0.517	0.562	0.766
^{237}Np	0.242	0.153	0	0.162	0.357	0	0.446	0.438	0.438	0.308	0.393	0.306
^{238}Pu	0.400	0.246	0	0.198	0.646	0.091	0.953	0.895	0.961	0.506	0.833	0.485
^{239}Pu	0.400	0.246	0	0.198	0.646	0.090	0.953	0.895	0.961	0.506	0.833	0.484
^{240}Pu	0.400	0.246	0	0.198	0.646	0.090	0.953	0.895	0.961	0.506	0.833	0.485
^{242}Pu	0.400	0.246	0	0.198	0.646	0.090	0.953	0.895	0.961	0.506	0.833	0.484
^{241}Am	0.404	0.252	0	0.231	0.646	0.096	0.959	0.905	0.958	0.532	0.835	0.513
^{243}Am	0.387	0.236	0.256	0.424	0.623	0.159	0.949	0.957	0.908	0.704	0.809	0.679

Table 6.2-5. Rank Correlations (Correlation Coefficients) Among the External Exposure-Ingestion-Radon BDCF Components for Individual Radionuclides (Continued)

	^{233}U	**^{234}U**	**^{236}U**	**^{238}U**	**^{237}Np**	**^{238}Pu**	**^{239}Pu**	**^{240}Pu**	**^{242}Pu**	**^{241}Am**	**^{243}Am**
^{90}Sr											
^{99}Tc											
^{126}Sn											
^{137}Cs											
^{210}Pb											
^{226}Ra											
^{227}Ac											
^{229}Th											
^{230}Th											
^{232}Th											
^{231}Pa											
^{232}U											
^{233}U	1.000										
^{234}U	1.000	1.000									
^{236}U	1.000	1.000	1.000								
^{238}U	0.981	0.981	0.981	1.000							
^{237}Np	0.345	0.345	0.345	0.355	1.000						
^{238}Pu	0.670	0.670	0.670	0.657	0.448	1.000					
^{239}Pu	0.670	0.670	0.670	0.657	0.448	1.000	1.000				
^{240}Pu	0.670	0.670	0.670	0.657	0.448	1.000	1.000	1.000			
^{242}Pu	0.670	0.670	0.670	0.657	0.448	1.000	1.000	1.000	1.000		
^{241}Am	0.674	0.674	0.674	0.667	0.450	0.990	0.990	0.990	0.990	1.000	
^{243}Am	0.652	0.652	0.652	0.694	0.450	0.940	0.940	0.940	0.940	0.959	1.000

Sources: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150], MO0306MWDBGSMF.001 [DIRS 163816].

NOTES: Calculated in Excel file *VA BDCF MC Correlations_Rev 3.xls* as shown in Appendix B.

Correlation coefficients for the short-term and long-term inhalation components are equal to unity.

Table 6.2-6. Calculated Values of Correlation Coefficient and Variable *t*

Calculated Correlation Coefficient, r	t
0.0000	0.000
0.0100	0.316
0.0200	0.632
0.0300	0.948
0.0400	1.265
0.0500	1.582
0.0600	1.899
0.0610	1.931
0.0620	1.962
0.0630	1.994
0.0700	2.217
0.0780	2.472
0.0790	2.504
0.0800	2.535
0.0810	2.567
0.0812	2.574
0.0813	2.577
0.0820	2.599
0.1000	3.175
0.1200	3.819
0.1400	4.467
0.1600	5.121
0.1800	5.781
0.2000	6.449

Source: Calculated in Excel file *VA BDCF MC Correlations_Rev 3.xls* as shown in Appendix B.

6.2.4 Pathway Analysis

The exposure pathway contributions to the BDCFs for volcanic ash exposure scenario are time-dependent and also depend on the thickness of contaminated ash layer. The pathway analysis was first conducted for the initial ash deposition at t = 0 before the mass loading decrease occurs, and the ash layer thickness equal to of less than the critical thickness ($d_a \le d_c$). For such conditions, the values functions $f(t)$ and $g(d_a)$ in Equations 6.2-1 to 6.2-3 are equal to unity. From Equations 6.2-1 to 6.2-3, when $t = 0$ and $d_a \le d_c$, then

$$BDCF_i(d_a, t) = BDCF_{ext,ing,Rn,i} + BDCF_{inh,v,i} + BDCF_{inh,p,i} \qquad \text{(Eq. 6.2-9)}$$

The percentage contributions of individual exposure pathways to the mean volcanic ash exposure scenario BDCFs at $t = 0$ and $d_a \le d_c$ are listed in Table 6.2-7.

Table 6.2-7. Exposure Pathway Contributions (Percent) for the Mean Volcanic Ash Exposure Scenario Biosphere Dose Conversion Factors for the Present-Day Climate

Radio-nuclide	External	Inhalation			Ingestion								
		Short	Long	Radon	Leafy Veget.	Other Veget.	Fruit	Grain	Meat	Milk	Poultry	Eggs	Soil
^{90}Sr	7.2	14.4	28.7	0.0	11.7	9.0	12.2	0.9	5.6	6.9	0.1	2.7	0.8
^{99}Tc	0.3	2.6	5.1	0.0	20.1	4.4	17.2	0.9	7.0	25.7	0.2	16.4	0.0
^{126}Sn	99.1	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
^{137}Cs	98.1	0.3	0.5	0.0	0.0	0.0	0.1	0.0	0.3	0.2	0.2	0.2	0.0
^{210}Pb	0.1	31.9	63.6	0.0	0.5	0.2	1.0	0.1	0.1	0.1	0.0	1.5	0.9
^{226}Ra	36.5	8.5	17.0	37.5	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1
^{227}Ac	0.0	33.4	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{229}Th	0.1	33.3	66.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{230}Th	0.0	33.4	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{232}Th	0.9	33.1	66.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{231}Pa	0.0	33.4	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{232}U	1.0	33.0	65.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{233}U	0.0	33.4	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{234}U	0.0	33.4	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{236}U	0.0	33.4	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{238}U	0.2	33.3	66.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{237}Np	0.3	33.2	66.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
^{238}Pu	0.0	33.4	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{239}Pu	0.0	33.4	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{240}Pu	0.0	33.4	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{242}Pu	0.0	33.4	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{241}Am	0.0	33.4	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{243}Am	0.4	33.2	66.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sources: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150], MO0306MWDBGSMF.001 [DIRS 163816].

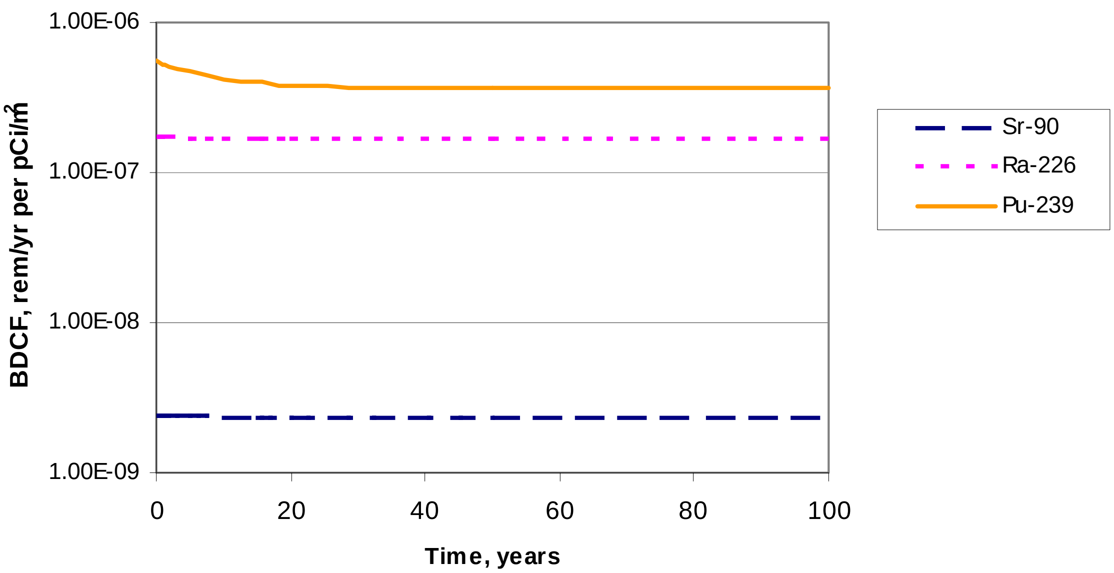
NOTES: Calculated in Excel file *VA BDCF MC Pathway Analysis_Rev 3.xls* as shown in Appendix B.
Veget. = vegetables

The evolution of BDCFs with time, which is controlled by the function *f(t)* shown in Equation 6.2-2, affects only the short-term inhalation component (see BSC 2004 [DIRS 169458], Section 6.3, for the development and detailed description of this function). The short-term inhalation component accounts for about one-third of the BDCF values presented in Table 6.2-7 for all actinides. For those radionuclides, the total mean BDCFs show a greater degree of reduction over time compared with radionuclides to smaller short-term inhalation components. This effect is shown in Figure 6.2-1 for ash thickness equal to 1 cm (10 mm) and the average value of the critical thickness (d_c = 2 mm). For such conditions, Equation 6.2-1 becomes

$$BDCF_i(t) = BDCF_{ext,ing,Rn,i} + \left(BDCF_{inh,v,i}\ e^{-0.125\,yr^{-1}\,t} + BDCF_{inh,p,i}\right)\frac{2\ mm}{10\ mm} \qquad \text{(Eq. 6.2-10)}$$

where 0.125 yr^{-1} is the value of mass loading decrease constant for ash thickness ≥ 10 mm (BSC 2004 [DIRS 169458], Section 7.1). The graph was plotted for ^{90}Sr, ^{226}Ra, and ^{239}Pu because of the differing pathway contributions for these radionuclides.

The mean BDCF for ^{90}Sr includes significant contributions from the external, inhalation, and ingestion exposure pathways. Ingestion is a relatively insignificant pathway for ^{226}Ra, while the mean BDCF for ^{239}Pu is dominated by inhalation.



Sources: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755] MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150], MO0306MWDBGSMF.001 [DIRS 163816].

NOTE: Calculated in Excel file *VA BDCF MC Pathway Analysis_Rev 3.xls* (Appendix B); ash thickness = 10 mm, critical thickness = 2 mm.

Figure 6.2-1. Mean Biosphere Dose Conversion Factors as a Function of Time

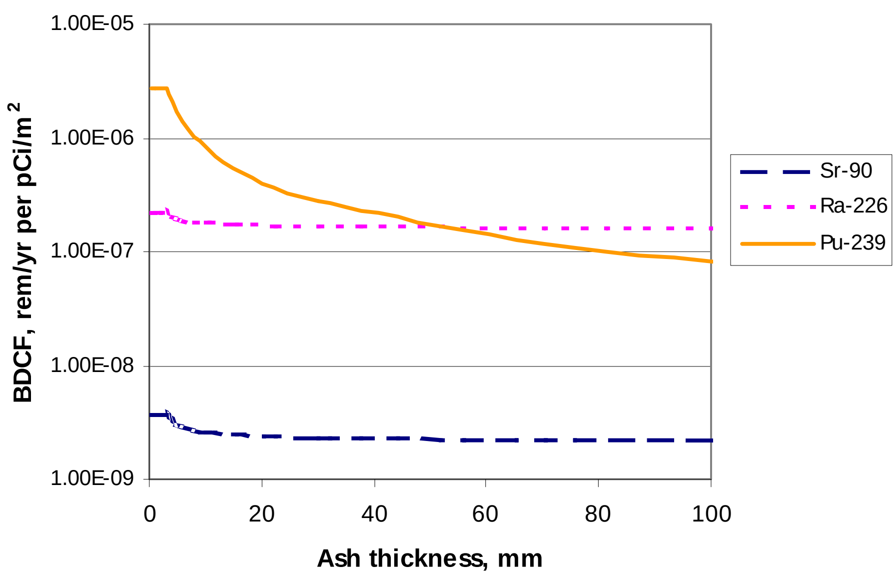
The short-term and the long-term inhalation components of BDCFs are affected by the thickness of the layer of contaminated ash. When the contaminated ash layer thickness is greater than the critical thickness, a fraction of the deposited activity is unavailable for resuspension; only the fraction equal to d_c/d_a can become resuspended. That is why the inhalation BDCF components are multiplied by d_c/d_a when $d_a>d_c$. For such conditions, when the ash thickness increases, a smaller fraction of the deposited activity would be available for resuspension because an increasing fraction would be in ash that is not subject to resuspension (i.e., below the critical thickness boundary). Consequently, the inhalation contribution would decrease. This effect, which is illustrated in Figure 6.2-2, would be strongest for radionuclides with large BDCF contribution from inhalation, such as ^{239}Pu. Figure 6.2-2 shows the BDCFs for the selected radionuclides as a function of ash thickness for the point-in-time conditions at t = 0 and for the maximum value of the critical thickness (d_c = 3 mm). For such conditions, Equation 6.2-1 becomes

$$BDCF_i(d_a) = BDCF_{ext,ing,Rn,i} + \left(BDCF_{inh,v,i} + BDCF_{inh,p,i}\right) g(d_a) \qquad \text{(Eq. 6.2-11)}$$

and the function of ash thickness $g(d_a)$, is expressed as

$$g(d_a) = \begin{cases} 1 & \text{when } d_a < 3mm \\ \dfrac{3mm}{d_a} & \text{when } d_a \geq 3mm \end{cases} \qquad \text{(Eq. 6.2-12)}$$

The maximum value of the critical thickness was used for the plots in Figure 6.2-2 to better show the "shoulder" of the curves, i.e., the region for $d_a < d_c$ where the BDCF does not depend on the ash thickness because the function $g(d_a)$ is constant.



Sources: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150], MO0306MWDBGSMF.001 [DIRS 163816].

NOTE: Calculated in Excel file *VA BDCF MC Pathway Analysis_Rev 3.xls* (Appendix B); critical thickness = 3 mm, time = 0 yr.

Figure 6.2-2. Mean Biosphere Dose Conversion Factors as a Function of Ash Thickness

6.2.5 Climate Change

Annual doses arising from volcanic eruption are calculated by combining the biosphere component (BDCFs) with the source term, i.e., the activity concentration of a given radionuclide per unit area (Equation 6.2-4). BDCFs are independent of the source term. The discussion of climate change presented here concerns only the biosphere component, the BDCFs, because the source term is calculated in the TSPA model.

A single biosphere model input parameter is affected by climate change: the growing time of crops for the human and animal consumption, which potentially may affect the ingestion exposure pathway. The ingestion exposure pathway contributes little to the BDCF for most radionuclides (Table 6.2-7). The importance of the ingestion pathway gradually increases as the short-term inhalation BDCF component decreases, so there is the potential for an increased effect of climate change on the BDCFs at later times.

Because climate change affects only the BDCF component associated with ingestion through the growing-time parameter, the value of this component was calculated for a future climate represented by the upper bound of the glacial transition climate. The results, in term of the ratios of the mean pathway BDCF values for the present-day and future climates, are presented in Table 6.2-8. The results of pathway analysis (Table 6.2-8) indicate that the biosphere modeling results for the volcanic release of radionuclides are relatively insensitive to the climate change.

The values in the table are ratios of the pathway BDCFs for the future and present-day climates. Since there is no difference between the inhalation, external exposure, and radon pathway contributions to BDCF for the present-day and future climates (climate-dependent parameters are not used to develop their values) and the difference between the ingestion pathway contributions are insignificant, it is recommended that the BDCFs developed for the present-day climate be used for the future climates.

Table 6.2-8. Ratio of Mean Ingestion Pathway Biosphere Dose Conversion Factors for the Volcanic Ash Exposure Scenario and the Future and Present-Day Climates

Radionuclide	Ingestion Pathway BDCF Ratio (Future Climate to Present-Day Climate)							
	Leafy Veget.	Other Veget.	Fruit	Grain	Meat	Milk	Poultry	Eggs
^{90}Sr	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{99}Tc	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{126}Sn	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{137}Cs	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{210}Pb	1.00	0.99	1.01	1.00	1.00	1.00	1.00	1.00
^{226}Ra	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00
^{227}Ac	1.00	0.98	1.02	1.00	1.00	1.00	1.00	1.00
^{229}Th	1.00	0.98	1.02	1.00	0.99	0.99	1.00	1.00
^{230}Th	1.00	1.02	0.98	1.00	1.01	1.01	1.00	1.00
$^{232}Th+^{228}Ra+^{228}Th$	1.00	0.99	1.01	1.00	1.00	1.00	1.00	1.00
^{231}Pa	1.00	0.99	1.01	1.00	1.00	1.00	1.00	1.00
$^{232}U+^{228}Th$	1.00	0.99	1.01	1.00	1.00	1.00	1.00	1.00

Table 6.2-8. Ratio of Mean Ingestion Pathway Biosphere Dose Conversion Factors for the Volcanic Ash Exposure Scenario and the Future and Present-Day Climates (Continued)

Radionuclide	Ingestion Pathway BDCF Ratio (Future Climate to Present-Day Climate)							
	Leafy Veget.	Other Veget.	Fruit	Grain	Meat	Milk	Poultry	Eggs
^{233}U	1.00	0.99	1.01	1.00	1.00	1.00	1.00	1.00
^{234}U	1.00	0.99	1.01	1.00	1.00	1.00	1.00	1.00
^{236}U	1.00	0.99	1.01	1.00	1.00	1.00	1.00	1.00
^{238}U	1.00	0.99	1.01	1.00	1.00	1.00	1.00	1.00
^{237}Np	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{238}Pu	1.00	0.97	1.02	1.00	0.99	0.99	1.00	1.00
^{239}Pu	1.00	0.97	1.02	1.00	0.99	0.99	1.00	1.00
^{240}Pu	1.00	0.97	1.02	1.00	0.99	0.99	1.00	1.00
^{242}Pu	1.00	0.97	1.02	1.00	0.99	0.99	1.00	1.00
^{241}Am	1.00	0.97	1.02	1.00	0.99	0.99	1.00	1.00
^{243}Am	1.00	0.97	1.02	1.00	0.99	0.99	1.00	1.00

Sources: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150], MO0306MWDBGSMF.001 [DIRS 163816].

NOTES: Calculated in Excel file *VA BDCF FC Pathway Analysis_Rev 3.xls* as shown in Appendix B.
Veget. = vegetables

6.3 DOSE FACTORS FOR THE ERUPTION PHASE

The eruption phase of a volcanic event refers to the conditions that exist during the volcanic eruption, before the deposition of volcanic ash on the ground is completed. This phase is not included in the calculation of BDCFs for volcanic ash exposure scenario because the BDCFs are calculated for the conditions that exist after the deposition took place. BDCFs include inhalation exposure to resuspended ash and contaminated soil, external exposure, and ingestion exposure and are calculated on the annual basis, regardless of the actual eruption time and day. The eruption phase is treated separately and its consequences are evaluated as those arising from the exposure occurring during an event of a limited duration (acute or near-acute exposure), rather than from a long-term, chronic exposure thereafter. The latter is evaluated using the BDCFs. The dose factor may be used in TSPA assessments to evaluate whether the doses received by the RMEI during an eruption need to be included in calculation of the expected dose.

Because higher concentrations of airborne radioactive particulates are expected in the air during this phase, inhalation of airborne contaminated ash particles is the only pathway considered in the analysis for this phase. The other possible pathways, such as external exposure from contaminated ash, are inherently included in the BDCFs (Section 6.2). Inhalation exposure arising from direct gaseous volcanic emissions was not considered because gaseous radionuclides were not included among radionuclides of interest (Section 6.1.1).

This section describes the development of the inhalation dose factor for the eruption phase (Section 6.3.2). To put the eruption phase into perspective, Section 6.3.1 contains a summary of mass loading measurements taken during volcanic eruptions. These values are presented for reference only but one could compare them with the values of mass loading used as input for the biosphere model to calculate volcanic ash scenario BDCFs.

6.3.1 Mass Loading Levels During Volcanic Eruption

This section is a summary of airborne particle concentration measurements taken during and immediately after volcanic eruptions. This summary is provided to develop an understanding of airborne concentrations of ash that may occur at the location of the receptor following a volcanic eruption at Yucca Mountain. This information may be used to support evaluation of receptor dose during a volcanic eruption, since the biosphere model does not evaluate receptor dose during the period of active ash fall. Inhalation dose from airborne particulate concentrations during volcanic eruption, if necessary, will be calculated as a component of performance assessment. The data presented in this section were not further used in this analysis.

The data in this section are from four volcanic eruptions at four widely spaced locations. Data at each location include measurements made over time and in different local collecting sites. Most of the measurements reported in this section were taken at ambient monitoring stations during or soon after ash-fall events. Ambient monitoring stations usually are centrally located in communities. The concentrations of airborne particles measured at those stations are representative of regional or local conditions that are not influenced by specific, immediately adjacent activities.

Mount St. Helens–Total suspended particulate (TSP) concentrations at Yakima, Washington, were as high as 35.6 mg/m^3 and averaged 13.3 mg/m^3 during the first week following the May 18, 1980 eruption of Mount St. Helens (Merchant et al. 1982 [DIRS 160102], pp. 912 to 913). Five to 10 mm of ash were deposited at Yakima during that eruption (Sarna-Wojcicki et al. 1982 [DIRS 160227], Figure 336).

The peak, short-term (about 4-hour) TSP concentration measured in Missoula, Montana, on May 19 (the day of greatest ash fall at that location) was 19.9 mg/m^3. The average daily concentrations there decreased from 11.1 mg/m^3 on May 19 to 0.9 mg/m^3 on May 22 (Johnson et al. 1982 [DIRS 164149], pp. 1067 to 1068). About 2.5 to 5 mm of ash was deposited at Missoula (Sarna-Wojcicki et al. 1982 [DIRS 160227], Figure 336).

The daily average TSP concentration in Clarkston, Washington, on May 18 was 0.68 mg/m^3. About 0.5 mm of ash was deposited there from that day's eruption. At Longview, Washington, the average daily concentration on May 27 was 1.42 mg/m^3. About 1 to 2 mm of ash was deposited on that city during an eruption on May 25 (DTN: MO0008SPATSP00.013 [DIRS 151750], EPA monitoring sites 53-003-0003 and 53-015-0008; Sarna-Wojcicki et al. 1982 [DIRS 160227], Figures 336 and 344).

About 10 percent or less of the ash from Mount St. Helens was ≤10 μm (PM_{10}) (Craighead et al. 1983 [DIRS 160338], p. 6; Buist et al. 1986[DIRS 144632], p. 40). PM_{10} is defined as particulate matter with mass median aerodynamic diameter less than 10 μm.

Soufriere Hills–Peak PM_{10} concentrations at 3 locations during an eruption of the Soufriere Hills volcano (Montserrat, British West Indies) in 1997 were about 0.3 to 1.0 mg/m^3 outside a school, 0.1 mg/m^3 inside that school, and 0.4 to 1.5 mg/m^3 outside a hotel (Baxter et al. 1999 [DIRS 150713], Figure 3 and p. 1142). The fine ashfall deposits from this volcano typically contained 60 to 70 percent (by weight) of 10 to 125 μm particles and 13 to 20 percent of particles <10 μm. Using a ratio of PM_{10} to TSP concentrations of 1:5 (calculated based on the average fraction of particles <10 μm in the deposited ash), peak TSP concentrations were about 1.5 to 5.0 mg/m^3, 0.5 mg/m^3, and 2.0 to 7.5 mg/m^3, respectively at the three locations. These concentrations likely did not include resuspended particles as they were taken late in the day after activities at the sites had ceased.

Searl et al. (2002 [DIRS 160104], Table 11) estimated mean personal PM_{10} exposure concentrations for various activity levels during and after eruptions of the Soufriere Hills volcano. Using a PM_{10} to TSP ratio of 1:5, estimated TSP concentrations during periods with alert levels to very high levels of ash were 1.5 to 5 mg/m^3 for people inactive indoors, 2.5 to 10 mg/m^3 for active indoors, 5 to 15 mg/m^3 for active outside, and 25 to 50 mg/m^3 for dusty occupations. These estimates include the influence of particle resuspension during activities.

Mt. Spurr–The maximum hourly PM_{10} concentration in Anchorage Alaska, during the 1992 eruption of Mt. Spurr was 3 mg/m^3. The 24-hour average concentrations the day after the eruption was 0.565 mg/m^3. About 8 to 15 percent (by weight) of ash particles from that eruption collected near Anchorage were <15 μm, and 5 to 10 percent were between 2.5 and 10 μm, resulting in an approximate PM_{10} to TSP ratio of 1:10. Based on this ratio, the peak TSP concentration in Anchorage was about 30 mg/m^3 and the 24-hour average was about 5.7 mg/m^3 (Gordian et al. 1996 [DIRS 160111], p. 290; McGimsey et al. 2001 [DIRS 160386], Figures 11 and 12).

Mt. Sakurijima–Yano et al. (1990 [DIRS 160112], p. 373) stated that peak, 2-minute concentrations higher than 2 mg/m^3 have been measured in high-exposure areas after eruptions of Mount Sakurijima (Japan), and that "these high levels of suspended particulate matter seldom last long, and they usually decrease rapidly to approximately 0.1 mg/m^3."

In summary, daily average concentrations of ash outdoors during an eruption may be as low or lower than 1 mg/m^3 for light ashfall events or as high or higher than 15 mg/m^3 for high ashfall events. Concentrations indoors would be much lower (see also BSC 2004 [DIRS 169458], Section 6.2). It should be noted that high ambient concentrations reported here do not result in an under-representation of the risk estimate because they likely are overestimates of concentrations inhaled because it is well documented that during volcanic eruptions people take actions, such as staying indoors and wearing masks, to reduce the amount of ash they inhale (Johnson et al. 1982 [DIRS 164149]; Buist et al. 1986 [DIRS 144632]; Nania et al. 1994 [DIRS 164156]).

6.3.2 Development of Dose Factors

As noted before, dose factors are developed to account for the inhalation exposure during an eruption phase. The dose factors are developed separately from BDCFs because BDCFs are developed for annual exposures and do not address relatively short-term exposure conditions during a volcanic eruption. The biosphere model described in the *Biosphere Model Report* (BSC 2004 [DIRS 169460]) is not used to calculate the dose factors.

The dose factor for a given primary radionuclide is numerically equal to the dose resulting from a one-day intake of this radionuclide (and associated short-lived decay products, if present) by inhaling air containing a unit activity concentration of the radionuclide under consideration (e.g., 1 Bq/m^3) and its short-lived decay products. For a unit activity concentration of a radionuclide in air, radionuclide intake depends on inhalation exposure time and breathing rate.

In the biosphere model, the dose to the RMEI from inhalation exposure to a given primary radionuclide i and its short-lived decay products present in airborne particulates is calculated (modified from annual dose to daily dose from BSC 2004 [DIRS 169460], Section 6.4.8.1) as

$$D_{inh,\,p,\,i} = EDCF_{inh,i}\left[\sum_{n} Ca_{\,i,n}\,BR_n \sum_{m}\left(PP_m\;t_{\,n,m}\right)\;\right] \qquad \text{Eq. 6.3-1}$$

where

$D_{inh,\,p,\,i}$	=	daily dose from inhalation exposure to primary radionuclide i in resuspended particles (Sv/d)
$EDCF_{inh,\,i}$	=	effective DCF for inhalation of primary radionuclide i (Sv/Bq)
n	=	environment index; n = 1 for active outdoors, 2 for inactive outdoors, 3 for active indoors, 4 for asleep indoors, and 5 for away from the contaminated area
$Ca_{i,\,n}$	=	activity concentration of primary radionuclide i in air for environment n (Bq/m^3)
BR_n	=	breathing rate for environment n (m^3/hr)
m	=	population group index; m = 1 for local outdoor workers, 2 for local indoor workers, 3 for commuters, and 4 for non-workers
PP_m	=	fraction of total population in population group m
$t_{\,n,\,m}$	=	number of hours per day a population group m spends in environment n (hr/d).

For calculating the inhalation dose, the exposure times for different population groups and environments, as well as the associated breathing rates, were developed (see Section 4.1 for a list of model input parameters). For the duration of volcanic eruption, environment-specific breathing rates and the fractions of time spent indoors versus outdoors are considered relatively unchanged compared to the pre-eruption conditions. Therefore, the same parameter values for lifestyle characteristics as those used for the BDCF calculation were used to develop dose factors for the eruption phase.

Because a volcanic eruption is an unusual event, it is possible that people would not behave as they would under normal circumstances. However, it is difficult to predict how the human behavior would change. Some people may seek shelter from falling ash and spend more time indoors where exposure would be reduced, while other people may, for instance, perform ash removal from their property and spend more time outdoors.

Ash depths 18 km downwind from Yucca Mountain were predicted to range from 0.07 to 55 cm (based on 100 realizations of the ASHPLUME model). About 35 percent of predicted depths were less than 1 cm, 75 percent were less than 5 cm, and 90 percent were less than 15 cm

(BSC 2004 [DIRS 170026], Table 6-4). Ash depths at the location of the RMEI (18 km south of Yucca Mountain) would be about 2 orders of magnitude or more lower under normal, variable wind conditions (CRWMS M&O 2000 [DIRS 153246], Section 3.10.5.1 and Figure 3.10-14) because the wind at Yucca Mountain blows to the south infrequently (BSC 2004 [DIRS 170026], Figure 8-1).

For the small amount of ashfall and an eruption lasting for several days, it is likely that the airborne particulate concentrations would not be substantially different from the pre-eruption levels. If this is the case, people would not modify their behavior to the extent that their overall average daily breathing rate would be affected, in which case the assumption is realistic. If airborne particulate concentrations were much greater than the pre-eruption levels, people would take actions to reduce the amount of ash they inhale, such as staying indoors and wearing masks (Section 6.3.1), and this assumption would lead to conservative results. In summary, using the same lifestyle characteristics parameter values for the eruption phase dose factors as those used for the volcanic ash exposure scenario BDCF calculations is considered technically defensible and not to result in an under-representation of the risk estimate.

It is further postulated that during volcanic eruption, the average level of mass loading indoors arising from the original deposition of tephra is one-half of that outdoors, or equivalently, the indoor reduction factor for activity concentration in air is equal to 0.5. This value does not concern activity concentrations resuspended due to atmospheric or mechanical processes following the initial deposition.

This indoor reduction factor is based on the ratio of the post-volcanic mass loading values indoor and outdoor in the absence of soil disturbing activities causing resuspension of deposited ash. Undisturbed conditions were chosen because the process of resuspension and the resulting inhalation of resuspended particulates are included in the BDCFs.

The ERMYN divides the biosphere into the five environments (BSC 2004 [DIRS 169671], Section 6.2). These mutually exclusive environments represent the behavioral and environmental combinations for which a person may receive a substantially different rate of exposure via inhalation or external exposure. These environments are:

Away from Potentially Contaminated Area environment accounts for time spent away from areas contaminated by groundwater or volcanic ash, including time spent working and commuting to work by those that work outside of contaminated areas.

Active Outdoors environment, which accounts for time spent active outdoors, includes time spent outdoors in contaminated areas conducting activities that resuspend soil.

Inactive Outdoors environment represents time spent commuting within contaminated areas and time spent outdoors in the contaminated areas conducting activities that do not resuspend soil.

Asleep Indoors includes time spent sleeping indoors within contaminated areas.

Active Indoors includes time spent awake, indoors within contaminated areas, including work time. It is calculated in the model as the remainder of the day not spent in the other environments.

Two environments that are not associated with soil disturbing activities are the inactive outdoor and asleep indoor environments. The modes of the mass loading distributions are 0.060 mg/m^3 and 0.030 mg/m^3 for the inactive outdoor and asleep indoor environments, respectively (DTN: MO0407SPAINEXI.002 [DIRS 170597]), indicating that dwellings provide about 50 percent reduction of the outdoor mass loading level.

Thus, assuming that the radionuclide concentration in the indoor air is a fraction of that in the outdoor air, Equation 6.3-1 can be modified as

$$\begin{aligned} D_{inh,p,i} &= EDCF_{inh,i}\left[\sum_n Ca_{i,outdoor}\ IRF_n\ BR_n \sum_m \left(PP_m\ t_{n,m}\right)\right] \\ &= Ca_{i,outdoor} EDCF_{inh,i}\left[\sum_n IRF_n\ BR_n \sum_m \left(PP_m\ t_{n,m}\right)\right] \\ &= Ca_{i,outdoor}\ DF_i \end{aligned} \qquad \text{(Eq. 6.3-2)}$$

where

$Ca_{i,outdoor}$	=	activity concentration of a radionuclide *i* in outdoor air for the ash that has not yet fallen on the ground (Bq/m^3)
IRF_n	=	indoor reduction factor for activity concentration in air (dimensionless)
DF_i	=	dose factor for a primary radionuclide *i* (Sv/d per Bq/m^3).

The activity concentration of a radionuclide *i* in outdoor air for the ash that has not yet fallen on the ground, $Ca_{i,outdoor}$, does not depend on the outdoor environment, as defined for the biosphere model (i.e., active outdoor and inactive outdoor), because this quantity is independent of human activities. The indoor reduction factor is equal to 1 for the outdoor environments (active outdoors and inactive outdoors) and to 0.5 for the indoor environments (asleep indoors and active indoors). The term in the brackets in Equation 6.3-2 is the effective daily breathing rate, i.e., the volume of outdoor air that contains the same amount of contaminant (radionuclide) as the air that is breathed in by a person in one day.

The dose factor in Equation 6.3-2 is expressed as

$$DF_i = EDCF_{inh,i}\left[\sum_n IRF_n\ BR_n \sum_m \left(PP_m\ t_{n,m}\right)\right] \qquad \text{(Eq. 6.3-3)}$$

The effective dose conversion factors for inhalation include, where applicable, contributions from the associated short-lived decay products. They were developed by calculating a sum of the dose conversion factors for inhalation, weighted by the associated branching fractions, as shown in Table 6.3-1. Dose conversion factors used in this analysis (DTN: MO0407SPACRBSM.002 [DIRS 170677]) are from Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069]). These DCFs were developed for radiation protection in the workplace and are usually applied to chronic low-dose, low-dose rate exposures. However, the same values are also recommended for conducting radiological assessments for consequence analysis in the case of accidental releases (Sjoreen et al. 2001 [DIRS 164093], Section 4.9.1), where calculated doses can exceed 250 rem (Sjoreen et al. 2001 [DIRS 164093], Table 7.1).

The dose factors are calculated as deterministic quantities using the mean values of parameters. They are provided to allow estimating the dose during the eruption phase. In the previous performance assessment, the dose calculated for the eruptive phase did not significantly contribute to the calculated expected annual dose, which was shown in the sensitivity analyses for the TSPA for the Site Recommendation (CRWMS M&O 2000 [DIRS 153246], Sections 3.10.3.1 and 5.2.9.9). Calculations of the individual terms in Equation 6.3-3 are shown in Table 6.3-2.

Table 6.3-1. Effective Dose Conversion Factors for Inhalation

Primary Radionuclide	Decay Product (branching fraction if not 100%, half-life)	Dose Conversion Factor (Sv/Bq)	Effective Dose Conversion Factor (Sv/Bq) [c]
Sr-90+D[a]		6.47E-08	6.70E-08
	Y-90 (64.0 hr)	2.28E-09	
Tc-99	-	2.25E-09	2.25E-09
Sn-126+D		2.69E-08	2.74E-08
	Sb-126m (19.0 min)	9.17E-12	
	Sb-126 (14%, 12.4 day)	3.17E-09	
Cs-137+D		8.63E-09	8.63E-09
	Ba-137m (94.6%, 2.552 min)	0.00E+00	
Thorium Series (4n)			
Pu-240	-	1.16E-04	1.16E-04
U-236	-	3.39E-05	3.39E-05
Th-232	-	4.43E-04	4.43E-04
Ra-228+D[b]		1.29E-06	1.37E-06
	Ac-228 (6.13 hr)	8.33E-08	
U-232	-	1.78E-04	1.78E-04
Th-228+D[b]		9.23E-05	9.32E-05
	Ra-224 (3.66 d)	8.53E-07	
	Rn-220 (55.6 s)	0.00E+00	
	Po-216 (0.15 s)	0.00E+00	
	Pb-212 (10.64 hr)	4.56E-08	
	Bi-212 (60.55 min)	5.83E-09	
	Po-212 (64.07%, 0.305 µs)	0.00E+00	
	Tl-208 (35.93%, 3.07 min)	0.00E+00	
Neptunium Series (4n + 1)			
Am-241	-	1.20E-04	1.20E-04
Np-237+D		1.46E-04	1.46E-04
	Pa-233 (27.0 d)	2.58E-09	
U-233	-	3.66E-05	3.66E-05

Table 6.3-1. Effective Dose Conversion Factors for Inhalation (Continued)

Primary Radionuclide	Decay Product (branching fraction if not 100%, half-life)	Dose Conversion Factor (Sv/Bq)	Effective Dose Conversion Factor (Sv/Bq) [c]
Neptunium Series (4n + 1)			
Th-229+D		5.80E-04	5.85E-04
	Ra-225 (14.8 d)	2.10E-06	
	Ac-225 (10.0 d)	2.92E-06	
	Fr-221 (4.8 min)	0.00E+00	
	At-217 (32.3 ms)	0.00E+00	
	Bi-213 (45.65 min)	4.63E-09	
	Po-213 (97.84%, 4.2 µs)	0.00E+00	
	Tl-209 (2.16%, 2.2 min)	0.00E+00	
	Pb-209 (3.253 hr)	2.56E-11	
Uranium Series (4n + 2)			
Pu-242	-	1.11E-04	1.11E-04
U-238+D		3.20E-05	3.20E-05
	Th-234 (24.10 d)	9.47E-09	
	Pa-234m (99.80%, 1.17 min)	0.00E+00	
	Pa-234 (0.33%, 6.7 hr)	2.20E-10	
Pu-238	-	1.06E-04	1.06E-04
U-234	-	3.58E-05	3.58E-05
Th-230	-	8.80E-05	8.80E-05
Ra-226+D		2.32E-06	2.32E-06
	Rn-222 (3.8235 d)	0.00E+00	
	Po-218 (3.05 min)	0.00E+00	
	Pb-214 (99.98%, 26.8 min)	2.11E-09	
	At-218 (0.02%, 2 s)	0.00E+00	
	Bi-214 (19.9 min)	1.78E-09	
	Po-214 (99.98%, 1.64×10^{-4} s)	0.00E+00	
	Tl-210 (0.02%, 1.3 min)	0.00E+00	
Pb-210+D		3.67E-06	6.26E-06
	Bi-210 (5.012 d)	5.29E-08	
	Po-210 (138.38 d)	2.54E-06	
Actinium Series (4n + 3)			
Am-243+D		1.19E-04	1.19E-04
	Np-239 (2.355 d)	6.78E-10	
Pu-239	-	1.16E-04	1.16E-04
U-235+D		3.32E-05	3.32E-05
	Th-231 (25.52 hr)	2.37E-10	
Pa-231	-	3.47E-04	3.47E-04

Table 6.3-1. Effective Dose Conversion Factors for Inhalation (Continued)

Primary Radionuclide	Decay Product (branching fraction if not 100%, half-life)	Dose Conversion Factor (Sv/Bq)	Effective Dose Conversion Factor (Sv/Bq) [c]
Actinium Series (4n + 3)			
Ac-227+D		1.81E-03	1.82E-03
	Th-227 (98.62%, 18.718 d)	4.37E-06	
	Fr-223 (1.38%, 21.8 min)	1.68E-09	
	Ra-223 (11.434 d)	2.12E-06	
	Rn-219 (3.96 s)	0.00E+00	
	Po-215 (1.78 ms)	0.00E+00	
	Pb-211 (36.1 min)	2.35E-09	
	Bi-211 (2.15 min)	0.00E+00	
	Tl-207 (99.72%, 4.77 min)	0.00E+00	
	Po-211 (0.28%, 0.516 s)	0.00E+00	
		0.00E+00	

DTN: MO0407SPACRBSM.002 [DIRS 170677].

[a] "+D" denotes that the radionuclide is treated together with the short-lived (half-life < 180 days) decay product.
[b] Indented radionuclides are long-lived decay products considered separately from the parents.
[c] Calculated as a sum of DCFs for primary radionuclides and the short-lived decay products, weighted by the branching fractions, where applicable.

Table 6.3-2. Supplementary Calculations Supporting Development of Dose Factors

	Proportion of Population, PP_m	**Mean Time Spent in Environment, $t_{n,m}$ (hours per day)**			
		Active Outdoors	**Inactive Outdoors**	**Asleep Indoors**	**Active Indoors**
Non-workers	39.20%	0.3	1.2	8.3	12.2
Commuters	12.50%	0.3	2	8.3	5.1
Local outdoor workers	5.50%	3.1	4.2	8.3	6.4
Local indoor workers	42.80%	0.3	1.5	8.3	11.9
Results of Calculation of Terms in Equation 6.3-3					
		Active Outdoors	**Inactive Outdoors**	**Asleep Indoors**	**Active Indoors**
$\sum_m \left(PP_m\ t_{n,m}\right)$ (hr/d)		0.454	1.593	8.3	10.865
BR_n (m³/hr)		1.57	1.08	0.39	1.08
IRF_n (dimensionless)		1	1	0.5	0.5
$IRF_n\ BR_n \sum_m \left(PP_m\ t_{n,m}\right)$ (m³/d)		0.713	1.721	1.619	5.867
$\sum_n IRF_n\ BR_n \sum_m \left(PP_m\ t_{n,m}\right)$ (m³/d)	**9.92**				

Source: MO0407SPACRBSM.002 [DIRS 170677].

NOTE: The symbols and formulas in the table are the same as those in Equation 6.3-3.

The dose factors for radionuclides of interest for the volcanic ash exposure scenario, in units of Sv/d per Bq/m^3 and rem/d per pCi/m^3, calculated using Equation 6.3-3, are summarized in Table 6.3-3. Calculations were performed in an Excel spreadsheet *Dose Factor Calculations_Rev 3.xls* (Appendix B).

Table 6.3-3. Inhalation Dose Factors for Eruptive Phase of the Volcanic Scenario

Radionuclide	Effective Dose Conversion Factor (Sv/Bq) [a]	Dose Factor [b]	
		Sv/d per Bq/m^3	rem/d per pCi/m^3
^{90}Sr	6.70E-08	6.65E-07	2.46E-06
^{99}Tc	2.25E-09	2.23E-08	8.26E-08
^{126}Sn	2.74E-08	2.72E-07	1.01E-06
^{137}Cs	8.63E-09	8.56E-08	3.17E-07
^{210}Pb	6.26E-06	6.21E-05	2.30E-04
^{226}Ra	2.32E-06	2.30E-05	8.51E-05
^{227}Ac	1.82E-03	1.81E-02	6.68E-02
^{229}Th	5.85E-04	5.80E-03	2.15E-02
^{230}Th	8.80E-05	8.73E-04	3.23E-03
^{232}Th + ^{228}Ra + ^{228}Th	5.38E-04	5.33E-03	1.97E-02
^{231}Pa	3.47E-04	3.44E-03	1.27E-02
^{232}U + ^{228}Th	2.71E-04	2.69E-03	9.95E-03
^{233}U	3.66E-05	3.63E-04	1.34E-03
^{234}U	3.58E-05	3.55E-04	1.31E-03
^{236}U	3.39E-05	3.36E-04	1.24E-03
^{238}U	3.20E-05	3.17E-04	1.17E-03
^{237}Np	1.46E-04	1.45E-03	5.36E-03
^{238}Pu	1.06E-04	1.05E-03	3.89E-03
^{239}Pu	1.16E-04	1.15E-03	4.26E-03
^{240}Pu	1.16E-04	1.15E-03	4.26E-03
^{242}Pu	1.11E-04	1.10E-03	4.07E-03
^{241}Am	1.20E-04	1.19E-03	4.40E-03
^{243}Am	1.19E-04	1.18E-03	4.37E-03

[a]From Table 6.3-1.
[b]Calculated by multiplying the effective dose conversion factor for inhalation by the term calculated in Table 6.3-2 (9.92 m^3/d).
The calculations are shown in Excel spreadsheet *Dose Factor Calculations_Rev 3.xls* (Appendix B).

7. CONCLUSIONS

This section summarizes the derivation of volcanic ash exposure scenario BDCF values and recommendations for their use in the TSPA model, as well as the derivation of inhalation dose factor values for the eruption phase of the volcanic event. The output of this analysis is included in several data sets, as shown in Table 7-1.

Table 7-1. Output Data Tracking Numbers

DTN	DTN Title	DTN Description and Comments
MO0307MWDDEBDC.001	Disruptive Event Biosphere Dose Conversion Factors	BDCFs for volcanic ash exposure scenario and inhalation dose factors for eruptive phase developed in Revision 2 of this analysis (BSC 2003 [DIRS 163958])
MO0407MWDBMVAE.000	Biosphere Dose Conversion Factors for the Volcanic Ash Exposure Scenario	BDCFs for the volcanic ash exposure scenario developed in this analysis.
MO0407SPADFIDV.000	Dose Factors for Calculating Inhalation Dose During Volcanic Eruption	Dose factors for calculating inhalation dose during volcanic eruption
MO0407MWDGSMFV.000	GoldSim Biosphere Model Files for Calculating Biosphere Dose Conversion Factors for Volcanic Ash Exposure Scenario	GoldSim and files generated in this analysis

The output of this analysis includes the new data (DTNs MO0407MWDBMVAE.000, MO0407SPADFIDV.000, and MO0407MWDGSMFV.000) as well as the re-qualified results (DTN: MO0307MWDDEBDC.001) from Revision 02 of the analysis (BSC 2003 [DIRS 163958]). The output of the previous analysis included in one DTN two data sets: BDCFs for the volcanic ash exposure scenario and the inhalation dose factors for the eruptive phase. The BDCFs from that data set are compared to the new BDCFs developed in this analysis (DTN: MO0407MWDBMVAE.000) in Appendix C.

The results of the impact analysis presented in Appendix C (see Section C.3 for conclusions) indicate that the differences between the BDCFs included in DTN: MO0307MWDDEBDC.001 and those in DTN: MO0407MWDBMVAE.000 are negligible and either DTN can be used in the TSPA model as a source of BDCFs. The impact was evaluated by comparing the mean, 5th percentile and 95th percentile values for the BDCF components. For both inhalation components, the differences between the values of these statistics do not exceed 10 percent. For the ingestion/external/radon component, the difference exceeds 10 percent in only one case: the 95th percentile value for ^{237}Np, and it is about 23 percent. However, for this radionuclide ingestion and external exposure pathways are negligible contributors for the all-pathway dose (radon pathway is not applicable for this radionuclide). It can thus be concluded that both BDCF sets can be used interchangeably.

The DTN: MO0307MWDDEBDC.001 includes dose factors for evaluating daily inhalation doses during a volcanic eruption. The inhalation dose factors in the DTN: MO0407SPADFIDV.000, which is an output of this analysis, are the same except for the values for ^{90}Sr, which differ by about 0.3 percent due to rounding. This difference is negligible and both sets can be used interchangeably.

The values of the BDCFs were developed using the ERMYN biosphere model and remain valid within the application and validation limits of the model (BSC 2004 [DIRS 169460], Section 8.2). Specifically, the BDCFs were developed for a specific assessment context, described in the *Biosphere Model Report* (BSC 2004 [DIRS 169460]), the reference biosphere, and the receptor. If used for other situations, the BDCFs may not apply.

For the contaminated volcanic ash exposure scenario, the model applies to a layer of small ash particles that could be resuspended into the air. The model and the BDCFs do not apply to other volcanic media, such as contaminated gas, lava, or coarse ash. Some assumptions regarding the model development (BSC 2004 [DIRS 169460], Section 6.3.2.4) are based on thin ash deposits; if thick ash deposits occur, the model might overestimate the BDCF values. For example, the external exposure is assumed in the biosphere model to originate from a contaminated ground surface. If the deposit were thick, the external exposure would be reduced because of self-absorption of the fraction of radiation emitted from contaminated ash/soil. The biosphere model assumes that the entire deposited activity is mixed into the surface soil and available to plants. For the deposits thicker than the rooting depth of plants, a portion of the deposited activity would not be available for plant uptake.

The ERMYN model does not apply during a volcanic eruption when volcanic ash is still in the air (i.e., before initial settling on the ground). For the eruption period, the inhalation dose factors should be used.

7.1 ANALYSIS SUMMARY

7.1.1 Incorporation of Uncertainty

The outputs of the biosphere model are BDCFs for volcanic ash exposure scenario. To incorporate uncertainty in the model input, BDCFs were calculated in a series of 1,000 model realizations. The resulting probability distribution represents uncertainty in the BDCFs. The full set of BDCFs consists of the three BDCF components generated for each of 23 primary radionuclides and each model realization. The summary of these results, in the form of discrete cumulative probability distributions of BDCFs in 5 percentile increments, plus means and standard deviations, is presented in Tables 6.2-1 to 6.2-3 for the external exposure-ingestion-radon component, short-term inhalation component, and the long-term inhalation component, respectively. The full set of BDCF vectors for each realization is included on a CD-ROM (Appendix B) in the file *VA BDCF Realizations MC_Rev 3.xls*.

Consideration of uncertainty was not included in the calculation of the dose factors because these parameters were developed as a scoping tool for the TSPA, as explained in Section 6.3.2.

7.1.2 Format of the Biosphere Dose Conversion Factor Input to TSPA

Three BDCF components are calculated for each primary radionuclide (Section 6.2.2). The first component, $BDCF_i$, is time independent and accounts for three exposure pathways (ingestion, inhalation of radon decay products, and external exposure). The second and third BDCF components account for inhaling airborne particulates. Both of these components depend on ash thickness. The second term ($BDCF_{inh,v,i}$) represents short-term inhalation exposure during increased concentrations of airborne particulates following volcanic eruption and is time-dependent because mass loading will gradually decrease after an eruption. The third term ($BDCF_{inh,p,i}$) represents long-term inhalation of suspended particulates under nominal conditions (i.e., when the mass loading is not elevated as the result of volcanic eruption). The results of the BDCF calculations are in the format of 1,000 row vectors, one for each model realization, consisting of three BDCF components for each of the 23 primary radionuclides (i.e., 69 BDCF components per vector) and a value of critical thickness of ash corresponding to the specific BDCF vector. A vector can be regarded as a one-dimensional array containing the results of a single realization of the biosphere model for the primary radionuclides.

Some BDCFs include contributions from their decay products. The primary radionuclides (radionuclides tracked in the TSPA) and the decay products, which were included in the BDCF with the primary radionuclides, are shown in Table 7.1-1.

Table 7.1-1. Primary Radionuclides and Their Decay Products Included in the Biosphere Dose Conversion Factors for the Volcanic Ash Exposure Scenario

Primary Radionuclide	Short-lived Decay Products Included in BDCF
Sr-90	Y-90
Tc-99	
Sn-126	
Cs-137	Ba-137m
Pb-210	Bi-210, Po-210
Ra-226	Rn-222, Po-218, Pb-214, At-218, Bi-214, Po-214, Tl-210
Ac-227	Th-227, Fr-223, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207, Po-211
Th-229	Ra-225, Ac-225, Fr-221, At-223, Bi-213, Po-213, Tl-209, Pb-209
Th-230	
Th-232	Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208
Pa-231	
U-232	Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208
U-233	
U-234	
U-236	
U-238	Th-234, Pa-234m, Pa-234
Np-237	Pa-233
Pu-238	
Pu-239	
Pu-240	
Pu-242	
Am-241	
Am-243	Np-239

7.1.3 Use of Biosphere Dose Conversion Factors for Volcanic Ash Exposure Scenario

Calculating the annual all-pathway dose for any given primary radionuclide is done by combining the source term with the BDCFs. In the case of the volcanic ash exposure scenario, the mass-loading decrease function and the ash thickness also are factored into the calculations. The total annual dose is the sum of the annual doses from individual radionuclides tracked in the TSPA (primary radionuclides), including their decay products. The total annual dose, computed by the TSPA model, is calculated as

$$
\begin{aligned}
D_{total}(d_a, t) &= \sum_i BDCF_i(d_{a,} t) \times Cs_i(t) \\
&= \sum_i BDCF_{ext,ing,Rn,i} \times Cs_i(t) \\
&\quad + \sum_i \left(BDCF_{inh,v,i}\, f(t) + BDCF_{inh,p,i} \right) g(d_a) \times Cs_i(t)
\end{aligned}
\qquad \text{(Eq. 7.1-1)}
$$

where

$D_{total}(d_a,t)$	=	time- and ash thickness-dependent total annual dose to a defined receptor resulting from the volcanic release of radionuclides from the repository (Sv/yr)
$Cs_i(t)$	=	time dependent activity concentration of radionuclide *i* in volcanic ash deposited on the ground (Bq/m^2)
$BDCF_i(d_a,t)$	=	BDCF for primary radionuclide *i* for an ash depth d_a at time *t* following a volcanic eruption (Sv/yr per Bq/m^2)
$BDCF_{ext,ing,Rn,i}$	=	BDCF for primary radionuclide *i* for external exposure, ingestion, and inhalation of radon decay products (Sv/yr per Bq/m^2)
$BDCF_{inh,v,i}$	=	BDCF for primary radionuclide *i* for short-term inhalation at post-volcanic level of mass loading in excess of nominal mass loading (Sv/yr per Bq/m^2)
$BDCF_{inh,p,i}$	=	BDCF for primary radionuclide *i* for long-term inhalation at nominal level of mass loading (Sv/yr per Bq/m^2).

The time function, *f(t)*, accounts for the reduction of mass loading in the years immediately following volcanic eruption. The mass loading is assumed to decrease exponentially with time as

$$f(t) = e^{-\lambda t} \qquad \text{(Eq. 7.1-2)}$$

where

λ	=	mass loading decrease constant (1/yr)
t	=	time (years); t = 0 is the first year after a volcanic eruption.

The mass loading decrease constant (Equation 7.1-2) depends on the ash thickness, and for an initial ash depth of less than 10 mm, it is represented by a triangular probability distribution function with a mode of 0.33/yr, a minimum of 0.2/yr, and a maximum of 2.0/yr (DTN: MO0407SPAINEXI.002 [DIRS 170597]). For an initial ash depth of 10 mm or more, the mass loading decrease constant is represented by a triangular distribution with a mode of 0.20/yr, a minimum of 0.125/yr, and a maximum of 1.0/yr (DTN: MO0407SPAINEXI.002 [DIRS 170597]).

The function of ash thickness, $g(d_a)$, is expressed as

$$g(d_a) = \begin{cases} 1 & \text{when } d_a < d_c \\ \dfrac{d_c}{d_a} & \text{when } d_a \geq d_c \end{cases} \qquad \text{(Eq. 7.1-3)}$$

where

d_c = critical thickness of ash layer (mm)

The value of the critical thickness is different for each biosphere model realization and has to be sampled in the TSPA code together with the BDCFs from the same vector.

An alternative method of using the volcanic ash scenario BDCFs can be offered for the situation when the radionuclide concentration in the resuspendable layer of surface soil of about 1-3 mm thickness (BSC 2004 [DIRS 169672], Section 6.8) is known. If this is the case, the annual dose can be calculated as

$$\begin{aligned} D_{total}(t) &= \sum_i BDCF_{ext,ing,Rn,i} \times Cs_i(t) \\ &+ \sum_i \left[BDCF_{inh,v,i}\, f(t) + BDCF_{inh,p,i} \right] \rho_a \times d_c \times Cs_{mc,i}(t) \end{aligned} \qquad \text{(Eq. 7.1-4)}$$

where

$Cs_{mc,i}$ = activity concentration of radionuclide i in the resuspendable ash or in the mix of ash and soil layer (Bq/kg)

ρ_a = settled density of ash (equal to 1000 kg/m^3 – see Table 4.1-1)

Equations shown above use SI units for consistency with the documentation of the ERMYN model (BSC 2004 [DIRS 169460]). However, any units can be used to define parameters in GoldSim, where the ERMYN model is implemented, as long as they are dimensionally consistent. The values of BDCF components in the output DTN are given in rem/yr per pCi/m^2.

7.1.4 Use of Dose Factors

For the eruption period, the dose factors for the inhalation exposure pathway should be used instead of the BDCFs. The dose factors for evaluating doses during volcanic eruptions are listed in Table 6.3-3. To calculate the daily dose from inhaling a specific radionuclide during a volcanic eruption, multiply the activity concentration of that radionuclide in air by the appropriate dose factors. The total inhalation dose, D_{inh}, from concentrations of primary radionuclides in air is then calculated as

$$D_{inh} = \sum_i D_{inh,i} = \sum_i DF_i \times Ca_{i,outdoor} \qquad \text{(Eq. 7.1-5)}$$

where

$D_{inh,\,i}$	=	daily inhalation dose for a primary radionuclide *i* (Sv/d or rem/d)
DF_i	=	dose factor for a primary radionuclide *i* (Sv/d per Bq/m^3 or rem/d per pCi/m^3)
$Ca_{i,outdoor}$	=	activity concentration of a primary radionuclide *i* in outdoor air for the ash that has not yet fallen on the ground (Bq/m^3 or pCi/m^3).

7.1.5 Correlations, Pathway Analysis, and Climate Change

Correlation coefficients for the BDCF components for each individual radionuclide are listed in Table 6.2-4. Rank correlations between the BDCF components of different radionuclides also have been calculated. Correlation coefficients for the external-ingestion-radon component are listed in Table 6.2-5. Correlation coefficients are the highest for the isotopes of actinides. Correlation coefficients for short-term and long-term inhalation components are equal to one.

Results of pathway analysis are presented in Table 6.2-7. The dominant pathway for actinide radionuclides is inhalation, with the long-term component contributing about 2/3 of the dose and the short-term component contributing about 1/3 of the dose. The pathway contributions for the other radionuclides are more diversified. For example, the food consumption pathways are dominant for ^{99}Tc, and the external exposure pathway is dominant for ^{137}Cs.

The climate change during the period of time considered in this analysis has negligible effects on the BDCFs for the volcanic ash exposure scenario because it primarily affects parameters related to irrigation and water use, which are not included in the model for the volcanic ash exposure scenario. It is thus recommended that the present-day climate BDCFs be used for dose assessment for the entire period.

7.2 HOW ACCEPTANCE CRITERIA WERE ADDRESSED

The primary function of this analysis was to calculate BDCFs for the volcanic ash exposure scenario. As noted before, this analysis thus integrates the model (BSC 2004 [169460]) and the model input parameters (BSC 2004 [DIRS 169671]; BSC 2004 [DIRS 169672]; BSC 2004 [DIRS 169673]; BSC 2004 [DIRS 169458]; and BSC 2004 [DIRS 169459]) to produce the output of the biosphere model. All acceptance criteria addressed by the model and input parameters reports are implicitly included in this analysis and the modeling results. The results reflect consideration of the site-specific FEPs, characteristics of the reference biosphere and its features, parameter selection and justification, as well as incorporation of uncertainty in the model and its input parameters. The model for the volcanic ash exposure scenario is briefly described in Section 6.1.5; the model input parameter values, including uncertainty distributions, are presented in Section 4.1.

In addition, the acceptance criteria, identified as applicable to this analysis in Section 4.2, that are related to the model abstraction were addressed. The biosphere modeling does not utilize the model abstraction step, but rather, the BDCF are calculated as the model output. In this sense, the BDCFs, which are the input to the TSPA model, serve as a "collapsed" model abstraction. The uncertainty in the model and its input parameters is propagated onto and reflected in the BDCFs through the development of the BDCF vectors representing individual model realizations (see Section 7.1.2), consistent with the acceptance criteria 2.2.1.3.13.3, 2.2.1.3.13.4, and 2.2.1.3.14.3 (see Table 4.2-2).

The specific acceptance criteria were addressed as follows.

2.2.1.3.13.3: Redistribution of Radionuclides in Soils

Acceptance Criterion 1 (1): As discussed in Sections 1 and 7.1.4, because the BDCFs are used directly in the TSPA, the TSPA adequately incorporates the redistribution of radionuclides contained in soils as a result of volcanic activity.

Acceptance Criterion 1(2): By including the BDCFs for disruptive events, the TSPA identifies and describes an aspect of radionuclide redistribution in soil that is important to repository performance. See, Section 7.1.2 and 7.1.3. The technical bases for the volcanic ash exposure scenario are adequately described in Section 6.1.2.

Acceptance Criterion 1 (3): Relevant site FEPs, including climate change (Section 6.1.3), receptor characteristics (Section 6.1.4), and the biosphere model (Section 6.1.5) have been appropriately modeled in the BDCFs. Sufficient technical bases are provided for the BDCFs.

Acceptance Criterion 1 (4): This report was developed in accordance with the QA procedures. It commits to NUREG-1297 and NUREG-1298. This commitment is implemented in project procedures. Compliance with project procedures is assessed through QA audits and other oversight activities.

Acceptance Criterion 2 (1): The BDCF development process described in Section 6 shows that the BDCFs used in the license application are justified. Adequate descriptions of how data was used to develop BDCFs are presented in Section 6.2, which includes pathway analysis (Section 6.2.4), climate change (Section 6.2.5), and uncertainty (Section 6.2.1).

Acceptance Criterion 2 (2): As shown in Sections 4.1.1 and 6.3.1, sufficient data are available to adequately define the parameters for the BDCFs.

Acceptance Criterion 3 (1): The calculations described in Section 6.2.2, the calculation results presented in Section 6.2.3, and the development of dose factors described in Section 6.3.2 show that the parameter values are technically defensible, reasonably account for uncertainties, and do not result in an under-representation of the risk.

Acceptance Criterion 3 (2): Section 6.3.1 shows that the data on the airborne particulate concentration is based on the resuspension of appropriate material in a climate and level of disturbance which is expected to be found at the location of the RMEI in the event of a volcanic eruption.

Acceptance Criterion 3 (3): Sections 6.2.1 and 7.1.1 shows that uncertainty was adequately represented in the BDCFs by a probability distribution which was generated from a thousand realizations using a Monte Carlo technique.

2.2.1.3.14.3: Biosphere Characteristics

Acceptance Criterion 1 (3): Section 6.2.6 shows how the impact of climate change on the BDCFs is consistent with assumptions about climate change in other TSPA abstractions.

Acceptance Criterion 1 (4): This report was developed in accordance with the QA procedures. It commits to NUREG-1297 and NUREG-1298. This commitment is implemented in project procedures. Compliance with project procedures is assessed through QA audits and other oversight activities.

Acceptance Criterion 2 (1): The BDCF development process described in Section 6 shows that the BDCFs used in the license application are justified. Adequate descriptions of how data was used to develop BDCFs are presented in Section 6.2, which includes a pathway analysis (Section 6.2.4), climate change (Section 6.2.5), and uncertainty (Section 6.2.1).

Acceptance Criterion 2 (2): As shown in Sections 4.1.1 and 6.3.1, sufficient data are available to adequately define the parameters for the BDCFs.

Acceptance Criterion 3 (1): Sections 6.2.3, 6.3.2, and 6.1.4 show that the parameter values are technically defensible, reasonably account for uncertainties, do not result in an under-representation of the risk, and are consistent with the definition of the RMEI.

Acceptance Criterion 3 (2): The technical bases for the BDCFs and inhalation dose factors are shown to be technically defensible by the Section 6.3.1 analysis of mass loadings measured at volcanic eruptions.

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MO0305SPAINEXI.001. Inhalation Exposure Input Parameters for the Biosphere Model. Submittal date: 05/27/2003. 163808

MO0305SPASRPBM.001. Soil Related Parameters for the Biosphere Model. Submittal date: 05/28/2003. 163815

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MO0306SPAAEIBM.001. Agricultural and Environmental Input Parameters for the 163812

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MO0307SEPFEPS4.000. LA FEP List. Submittal date: 07/31/2003. 164527

MO0307MWDDEBDC.001. Disruptive Event Biosphere Dose Conversion Factors. Submittal date: 07/08/2003. 164616

MO0407SEPFEPLA.000. LA FEP List. Submittal date: 07/20/2004. 170760

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MO0406SPAETPBM.002. Environmental Transport Input Parameters for the Biosphere Model. Submittal date: 06/24/2004. 170150

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8.4 SOFTWARE CODES

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BSC 2004. *Software Code: GoldSim.* V8.01 Service Pack 4. PC, Windows 2000. 10344-8.01SP4-00. 169695

8.5 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

MO0307MWDDEBDC.001	Disruptive Event Biosphere Dose Conversion Factors
MO0407MWDBMVAE.000	Biosphere Dose Conversion Factors for the Volcanic Ash Exposure Scenario

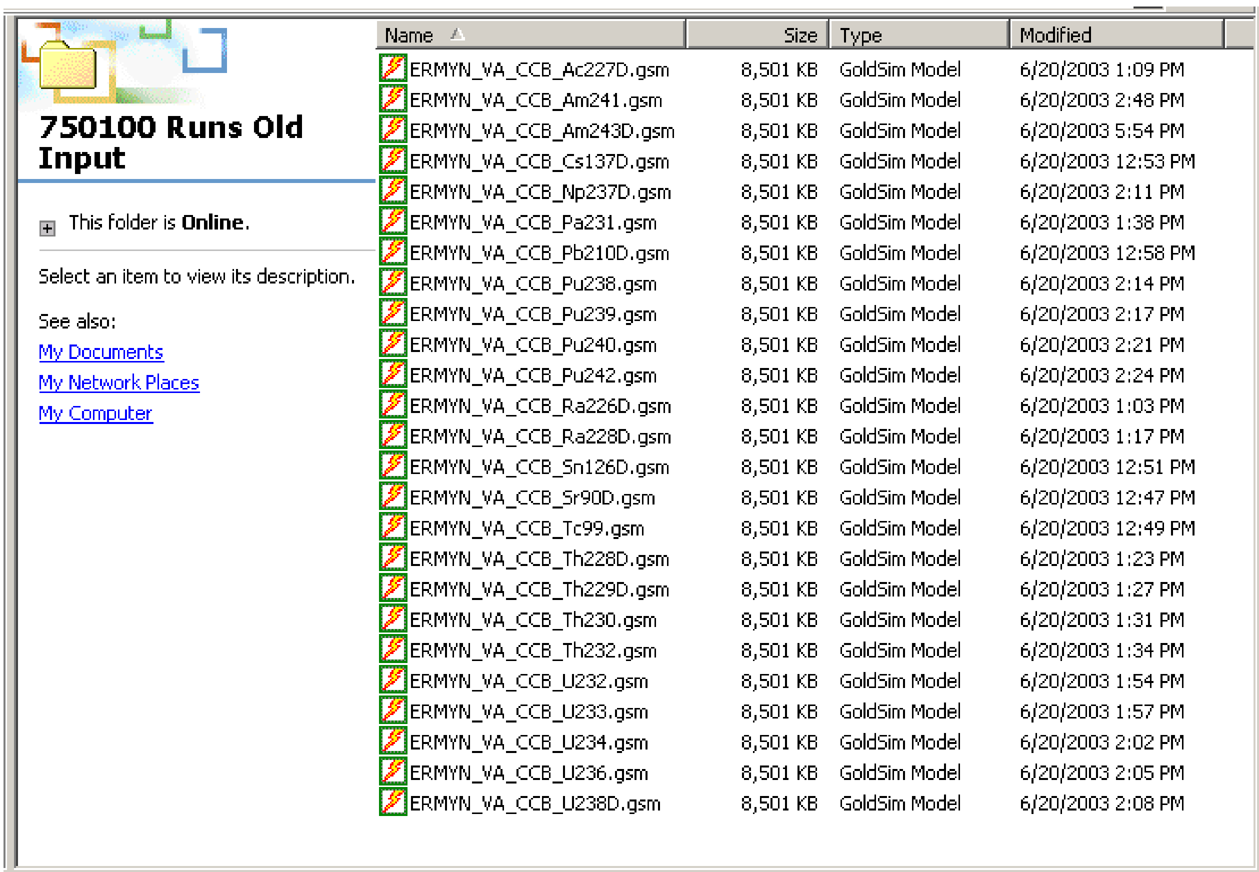
MO0407SPADFIDV.000	Dose Factors for Calculating Inhalation Dose During Volcanic Eruption
MO0407MWDGSMFV.000	GoldSim Biosphere Model Files for Calculating Biosphere Dose Conversion Factors for Volcanic Ash Exposure Scenario

APPENDIX A

LIST AND DESCRIPTION OF GOLDSIM FILES GENERATED IN THIS ANALYSIS

This appendix contains the list and description of GoldSim biosphere model files generated in this analysis. The files are included in DTN: MO0407MWDGSMFV.000, which is an output of this analysis. In addition to the files listed in this Appendix, DTN: MO0407MWDGSMFV.000 also includes verification files listed in Appendix E.

Figure A-1 shows the list of GoldSim files for the present-day climate (file names ERMYN_VA_CCB_<radionuclide symbol>) generated using GoldSim V7.50.100 and the old input parameter values (DTN: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]).


750100 Runs Old Input

This folder is **Online.**

Select an item to view its description.

See also:
My Documents
My Network Places
My Computer

Name	Size	Type	Modified
ERMYN_VA_CCB_Ac227D.gsm	8,501 KB	GoldSim Model	6/20/2003 1:09 PM
ERMYN_VA_CCB_Am241.gsm	8,501 KB	GoldSim Model	6/20/2003 2:48 PM
ERMYN_VA_CCB_Am243D.gsm	8,501 KB	GoldSim Model	6/20/2003 5:54 PM
ERMYN_VA_CCB_Cs137D.gsm	8,501 KB	GoldSim Model	6/20/2003 12:53 PM
ERMYN_VA_CCB_Np237D.gsm	8,501 KB	GoldSim Model	6/20/2003 2:11 PM
ERMYN_VA_CCB_Pa231.gsm	8,501 KB	GoldSim Model	6/20/2003 1:38 PM
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ERMYN_VA_CCB_U238D.gsm	8,501 KB	GoldSim Model	6/20/2003 2:08 PM

Figure A-1. GoldSim Files for Calculating BDCFs for the Present-Day Climate Using GoldSim V7.50.100 With Old Input Parameters

Figure A-2 shows the list of GoldSim files for the present-day climate (file names ERMYN_VA_MC8_<radionuclide symbol>) generated using GoldSim V8.01 SP4 and the new input parameter values (DTN: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150]).

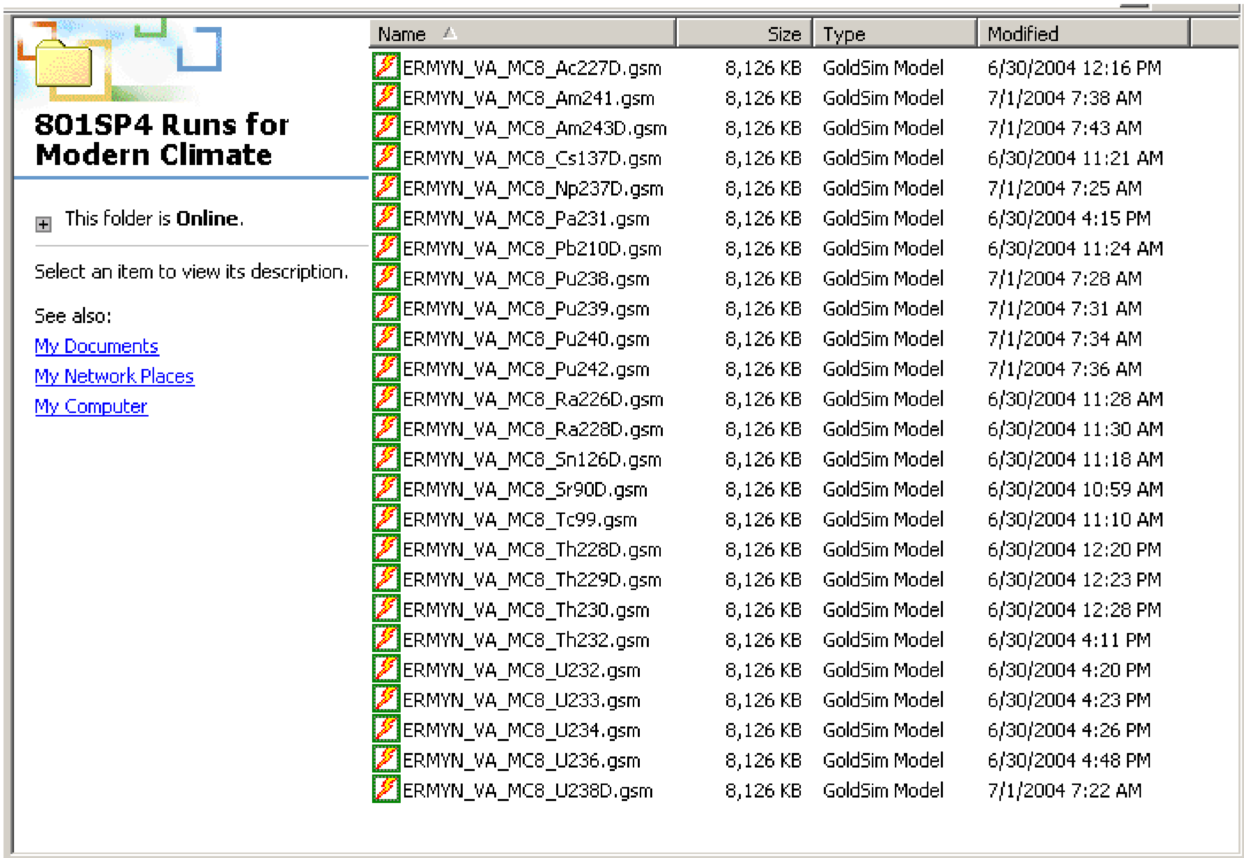
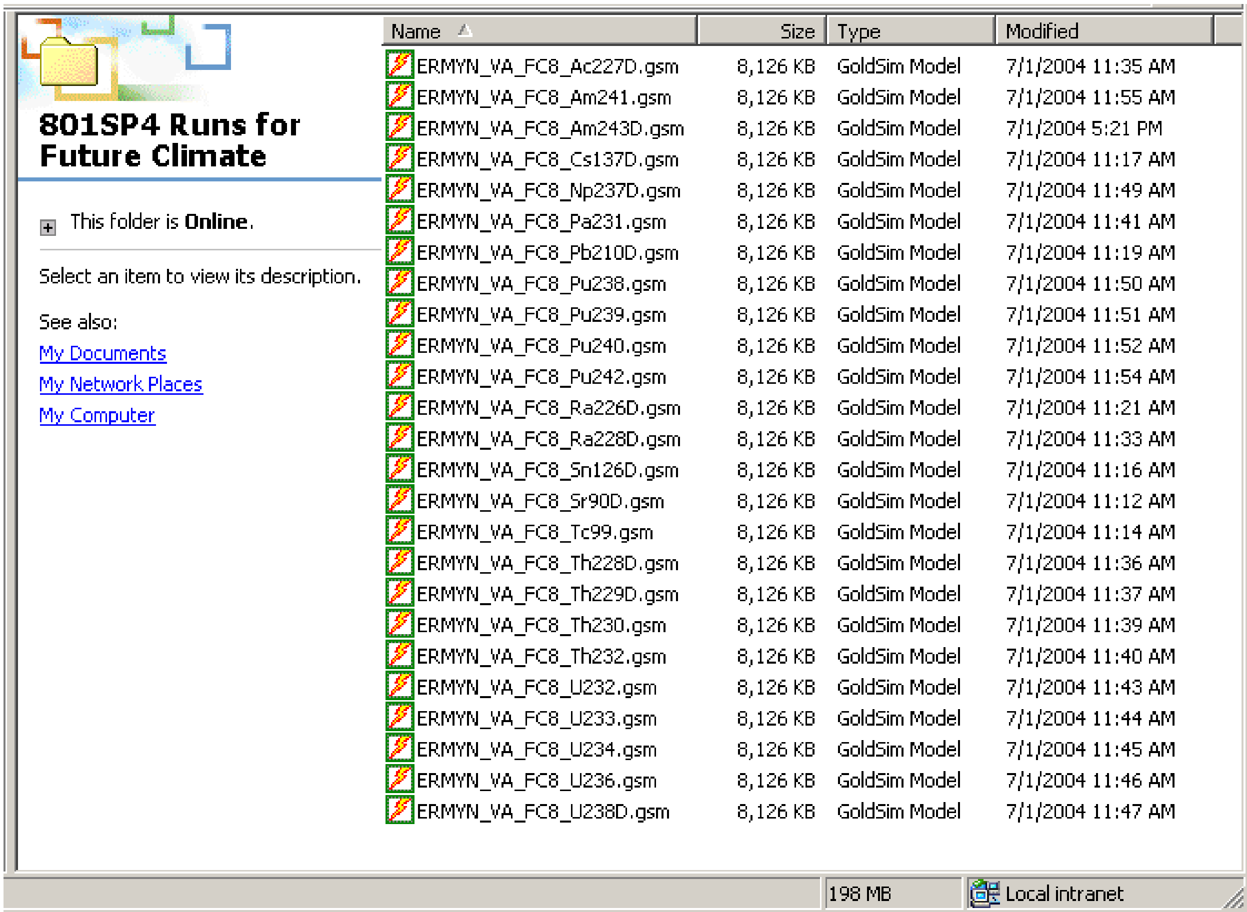


Figure A-2. GoldSim Files for Calculating BDCFs for the Present-Day Climate Using GoldSim V8.01 SP4 with New Input Parameters

Figure A-3 shows the list of GoldSim files for the upper bound of the glacial transition climate (file names ERMYN_VA_FC8_<radionuclide symbol>) generated using GoldSim V8.01 SP4 and the new input parameter values.



Name	Size	Type	Modified
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ERMYN_VA_FC8_Am241.gsm	8,126 KB	GoldSim Model	7/1/2004 11:55 AM
ERMYN_VA_FC8_Am243D.gsm	8,126 KB	GoldSim Model	7/1/2004 5:21 PM
ERMYN_VA_FC8_Cs137D.gsm	8,126 KB	GoldSim Model	7/1/2004 11:17 AM
ERMYN_VA_FC8_Np237D.gsm	8,126 KB	GoldSim Model	7/1/2004 11:49 AM
ERMYN_VA_FC8_Pa231.gsm	8,126 KB	GoldSim Model	7/1/2004 11:41 AM
ERMYN_VA_FC8_Pb210D.gsm	8,126 KB	GoldSim Model	7/1/2004 11:19 AM
ERMYN_VA_FC8_Pu238.gsm	8,126 KB	GoldSim Model	7/1/2004 11:50 AM
ERMYN_VA_FC8_Pu239.gsm	8,126 KB	GoldSim Model	7/1/2004 11:51 AM
ERMYN_VA_FC8_Pu240.gsm	8,126 KB	GoldSim Model	7/1/2004 11:52 AM
ERMYN_VA_FC8_Pu242.gsm	8,126 KB	GoldSim Model	7/1/2004 11:54 AM
ERMYN_VA_FC8_Ra226D.gsm	8,126 KB	GoldSim Model	7/1/2004 11:21 AM
ERMYN_VA_FC8_Ra228D.gsm	8,126 KB	GoldSim Model	7/1/2004 11:33 AM
ERMYN_VA_FC8_Sn126D.gsm	8,126 KB	GoldSim Model	7/1/2004 11:16 AM
ERMYN_VA_FC8_Sr90D.gsm	8,126 KB	GoldSim Model	7/1/2004 11:12 AM
ERMYN_VA_FC8_Tc99.gsm	8,126 KB	GoldSim Model	7/1/2004 11:14 AM
ERMYN_VA_FC8_Th228D.gsm	8,126 KB	GoldSim Model	7/1/2004 11:36 AM
ERMYN_VA_FC8_Th229D.gsm	8,126 KB	GoldSim Model	7/1/2004 11:37 AM
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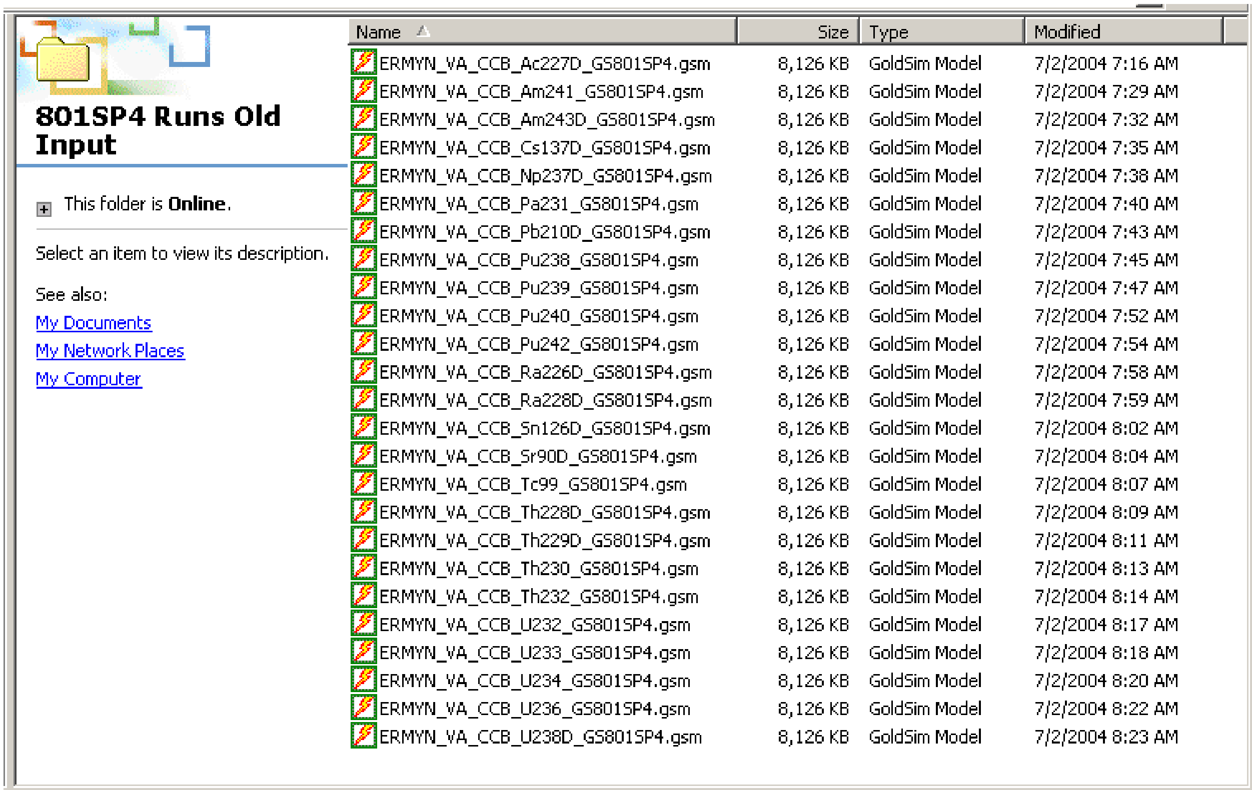
ERMYN_VA_FC8_U238D.gsm	8,126 KB	GoldSim Model	7/1/2004 11:47 AM

Figure A-3. GoldSim Files for Calculating BDCFs for the Upper Bound Glacial Transition Climate Using GoldSim V8.01 SP4 with New Input Parameters

Figure A-4 shows the list of GoldSim files for the present-day climate (file names ERMYN_VA_CCB_<radionuclide symbol>_GS801SP4) generated using GoldSim V8.01 SP4 and the old input parameter values.



Name	Size	Type	Modified
ERMYN_VA_CCB_Ac227D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:16 AM
ERMYN_VA_CCB_Am241_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:29 AM
ERMYN_VA_CCB_Am243D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:32 AM
ERMYN_VA_CCB_Cs137D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:35 AM
ERMYN_VA_CCB_Np237D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:38 AM
ERMYN_VA_CCB_Pa231_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:40 AM
ERMYN_VA_CCB_Pb210D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:43 AM
ERMYN_VA_CCB_Pu238_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:45 AM
ERMYN_VA_CCB_Pu239_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:47 AM
ERMYN_VA_CCB_Pu240_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:52 AM
ERMYN_VA_CCB_Pu242_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:54 AM
ERMYN_VA_CCB_Ra226D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:58 AM
ERMYN_VA_CCB_Ra228D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 7:59 AM
ERMYN_VA_CCB_Sn126D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:02 AM
ERMYN_VA_CCB_Sr90D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:04 AM
ERMYN_VA_CCB_Tc99_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:07 AM
ERMYN_VA_CCB_Th228D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:09 AM
ERMYN_VA_CCB_Th229D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:11 AM
ERMYN_VA_CCB_Th230_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:13 AM
ERMYN_VA_CCB_Th232_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:14 AM
ERMYN_VA_CCB_U232_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:17 AM
ERMYN_VA_CCB_U233_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:18 AM
ERMYN_VA_CCB_U234_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:20 AM
ERMYN_VA_CCB_U236_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:22 AM
ERMYN_VA_CCB_U238D_GS801SP4.gsm	8,126 KB	GoldSim Model	7/2/2004 8:23 AM

Figure A-4. GoldSim Files for Calculating BDCFs for the Present-Day Climate Using GoldSim V8.01 SP4 with Old Input Parameters

Figure A-5 shows the list of GoldSim files for the present-day climate (file names ERMYN_VA_MC7_NI_<radionuclide symbol>) generated using GoldSim V7.50.100 and the new input parameter values.

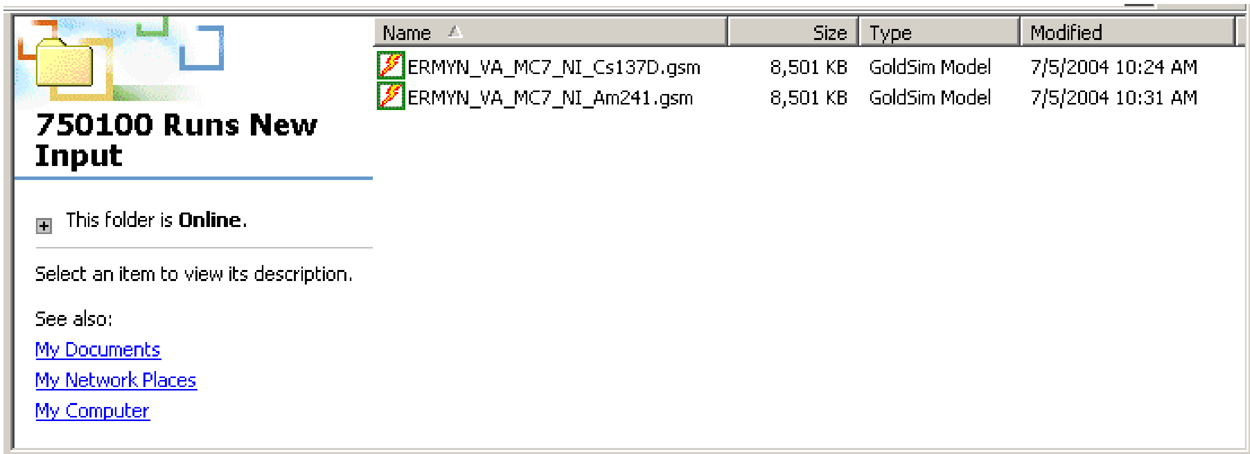


Figure A-5. GoldSim Files for Calculating BDCFs for the Present-Day Climate Using GoldSim V7.50.100 with New Input Parameters

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APPENDIX B

DESCRIPTION OF EXCEL FILES GENERATED IN THIS ANALYSIS

This appendix contains descriptions of the Microsoft Excel files that were used for calculations in this analysis. For the files that contain the stochastic results of the GoldSim runs, the values were copied from the RESULTS container of the appropriate GoldSim files and pasted into the worksheets.

B1. LIST OF EXCEL FILES

Figure B-1 shows the list of the Excel files supporting this analysis. The description of the files follows in Section B.2.

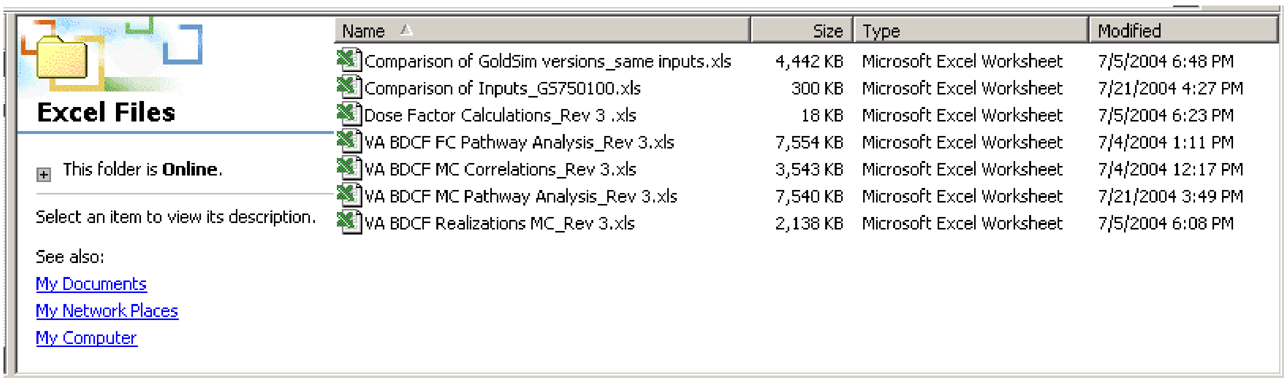

Figure B-1. List of Excel Files Supporting This Analysis

B2. DESCRIPTION OF EXCEL FILES

VA BDCF Realizations MC_Rev 3.xls–This Excel file contains the results of 1,000 biosphere model realizations that generated BDCFs for the volcanic ash exposure scenario for the present-day climate. The BDCFs are arranged by radionuclide in sets of four columns per radionuclide in Columns B to DE. For each realization and each radionuclide, three BDCF components were generated: external-ingestion-radon, short-term inhalation, and long-term inhalation. The fourth value per radionuclide is the critical thickness, which is the same for a given model realization for each radionuclide. The results of individual realizations are in rows 36 to 1,035. The values were copied from the GoldSim results summaries.

Row 7 contains the means of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel AVERAGE function for the specified cell range.

Row 8 contains standard deviations of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel STDEV function for the specified cell range.

Row 10 contains minima of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel MIN function for the specified cell range.

Row 30 contains maxima of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel MAX function for the specified cell range.

Rows 11 to 29 contain the percentiles in the increments of 5 of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel PERCENTILE function for the specified cell range.

VA BDCF MC Correlations_Rev 3.xls–This Excel file contains calculations of the rank correlation coefficients for the BDCF components.

The BDCFs are arranged by radionuclide in sets of 6 columns per radionuclide in Columns B to EI. For each realization and each radionuclide, the three BDCF components (external-ingestion-radon, short-term inhalation, and long-term inhalation) are in the first, third, and fifth column of each set of 6. The second, fourth and sixth column contain the rank of each adjacent cell, calculated using the Excel RANK function for the specified range of cells. The BDCF values and their ranks for individual model realizations are in rows 13 to 1,012.

Row 11 contains the correlation coefficients for the BDCF components for a given radionuclide. The rank correlation coefficients are in the second, fourth and sixth column of the set of 6 for each radionuclide. The correlation coefficients were calculated using the Excel CORREL function.

Rows 1,018 to 1,040 contain the 23 by 23 table of rank correlation coefficients for the external-ingestion-radon BDCF components for all 23 primary radionuclides.

The rows beneath contain supplementary calculations of the Student's *t* values for the range of correlation coefficient values and the summary of the BDCF component correlation coefficients shown in row 11 of the worksheet.

VA BDCF MC Pathway Analysis_Rev 3.xls–This Excel file contains calculations of pathway contributions to BDCFs for the present-day climate. The workbook consists of 28 worksheets, containing pathway BDCFs for individual realizations and individual radionuclides. The first worksheet (*Pathway Summary*) contains the summary of the mean pathway BDCFs. The second to twenty-eighth worksheets contain the pathway BDCFs from individual realizations for 23 primary radionuclides, 2 long-lived decay products, ^{228}Ra and ^{228}Th, and the 2 decay products combined with their respective primary radionuclide, i.e., ^{232}Th + ^{228}Ra + ^{228}Th and ^{232}U + ^{228}Th. The mean values are also included. The pathway BDCFs for 1,000 realizations are in rows 10 to 1,009 of each spreadsheet for an individual radionuclide. The values were copied from GoldSim pathway results summary, following each run of the model. Row 6 contains the mean values calculated using the Excel AVERAGE function.

The *Pathway Summary* worksheet contains the mean values of pathway BDCFs copied from the individual radionuclide worksheets. These values are shown in rows 9 to 35 for individual radionuclides and in Columns C to O for individual exposure pathways. Column P contains the sum of the external, ingestion and radon pathways. Column Q contains the total BDCF for a radionuclide, which is a sum of individual pathway BDCFs.

Rows 43 to 69 contain the calculated percent values of the individual pathway contributions to the total BDCF. These values were calculated by dividing the mean pathway BDCFs by the total BDCF for a given radionuclide. Rows 72 to 94 contain the percent pathway contributions for pasting into the report.

This file also generates the plots shown in Figures 6.2-1 and 6.2-2 in the *Pathway Summary* worksheet.

VA BDCF FC Pathway Analysis_Rev 3.xls–This Excel file contains calculations of pathway contributions to BDCFs for the future climate represented by the upper bound of the glacial transition climate. The workbook consists of 28 worksheets, containing pathway BDCFs for individual realizations and individual radionuclides. The first worksheet (*Pathway Summary*) contains a summary of the mean pathway BDCFs and a comparison with the present-day climate pathway BDCFs from file *VA BDCF MC Pathway Analysis_Rev 3.xls*. The layout of the workbook for the future climate is similar to the workbook for the present-day climate. The values were copied from the GoldSim pathway results summary, following each run of the model. Row 6 contains the mean values calculated using the Excel AVERAGE function.

The *Pathway Summary* worksheet contains the mean values of pathway BDCFs copied from the individual radionuclide worksheets. These values are shown in rows 9 to 35 for individual radionuclides and in Columns C to O for individual exposure pathways. Column P contains the sum of the external, ingestion and radon pathways. Column Q contains the total BDCF for a radionuclide, which is a sum of individual pathway BDCFs.

Rows 76 to 102 contain the summary of the present-day climate pathway BDCF results copied from the *VA BDCF MC Pathway Analysis_Rev 3.xls* file (*Pathway Summary* worksheet, rows 9 to 35). Rows 109 to 131 contain the ratios of pathway BDCFs for the future and the present-day climates.

Dose Factor Calculations_Rev 3.xls–This Excel file contains calculations of the inhalation dose factors computed using Equation 6.3-3.

Calculations of the effective breathing rate (term in the brackets in Equation 6.3-3) are in rows 10 to 19. Dose factors for individual radionuclides are calculated in rows 27 to 53. Column C contains the values of effective dose conversion factor for inhalation of a given radionuclide and its short-lived decay products, if applicable. Column D contains the value of the effective daily breathing rate calculated above. Columns E and F contain calculations of daily inhalation dose in Sv/d if the activity concentration in air is 1 Bq/ m^3 and in rem/d for activity concentration of 1 pCi/m^3, respectively. Daily doses are calculated as the product of daily activity intakes of a given radionuclide and the corresponding inhalation effective dose conversion factor.

Comparison of Inputs_GS750100.xls–This Excel file contains the results of the biosphere model runs using GoldSim 7.50.100 with new and with old inputs.

There are 1,000 biosphere model realizations for ^{137}Cs and for ^{241}Am with the new inputs (DTN: MO0406SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0406SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150]) and with the old inputs (DTN: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]). The BDCF components are arranged by radionuclide in sets of 3 columns per radionuclide and input type. Columns B to D contain the

BDCF components for ^{137}Cs and new inputs, columns E to G for the same radionuclide with the old inputs. In columns H to J, percent relative difference between the BDCF components calculated using the new and the old inputs are computed. Columns M to U contain an analogous set for ^{241}Am.

Row 6 contains the means of the values in rows 34 to 1,033 of the corresponding columns, calculated using the Excel AVERAGE function for the specified cell range.

Row 7 contains standard deviations of the values in rows 34 to 1,033 of the corresponding columns, calculated using the Excel STDEV function for the specified cell range.

Row 8 contains minima of the values in rows 34 to 1,033 of the corresponding columns, calculated using the Excel MIN function for the specified cell range.

Row 28 contains maxima of the values in rows 34 to 1,033 of the corresponding columns, calculated using the Excel MAX function for the specified cell range.

Rows 9 to 27 contain the percentiles in the increments of 5 of the values in rows 34 to 1,033 of the corresponding columns, calculated using the Excel PERCENTILE function for the specified cell range.

Comparison of GoldSim versions_same inputs.xls–This Excel file contains the results of the biosphere model runs using GoldSim versions 7.50.100 and 8.01 SP4 with the same inputs.

There are three worksheets in this workbook: *GS 7.50.100*, *GS 8.01 SP 4* and *Comparison*. The worksheet *GS 7.50.100* contains the results of the biosphere model runs using GoldSim V7.50.100 with the old inputs. The worksheet *GS 8.01 SP4* contains the results of the biosphere model runs using GoldSim V8.01 SP4 with the old inputs. The BDCFs are arranged by radionuclide in sets of 4 columns per radionuclide in Columns B to DE. For each realization and each radionuclide, three BDCF components were generated: external-ingestion-radon, short-term inhalation, and long-term inhalation. The fourth value per radionuclide is the critical thickness, which is the same for a given model realization for each radionuclide. The results of individual realizations are in rows 36 to 1,035. The values were copied from the GoldSim results summaries.

Row 7 contains the means of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel AVERAGE function for the specified cell range.

Row 8 contains standard deviations of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel STDEV function for the specified cell range.

Row 10 contains minima of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel MIN function for the specified cell range.

Row 30 contains maxima of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel MAX function for the specified cell range.

Rows 11 to 29 contain the percentiles in the increments of 5 of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel PERCENTILE function for the specified cell range.

The worksheet *Comparison* contains the summary of statistics from the worksheets *GS 7.50.100* and *GS 8.01 SP 4* in rows 8 to 30 and 39 to 61, respectively. In rows 68 to 90, percent relative difference between the BDCF statistics for the two GoldSim versions is calculated.

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APPENDIX C

ANALYSIS OF IMPACT OF SOFTWARE AND INPUT CHANGE ON THE MODELING RESULTS

This section presents the results of impact analysis regarding the input and software change between the Revision 02 of this analysis (BSC 2003 [DIRS 163958]) and the current revision. As a result of source data change and other improvements, the input data changed for a few model input parameters. Also, an inconsistency was discovered in the Latin Hypercube sampling scheme that was used by GoldSim V7.50.100, which was used to execute the biosphere model in Revision 02 of this analysis. The inconsistency was corrected in GoldSim V8.01.SP4, which was used to generate the volcanic ash exposure scenario BDCFs in this analysis. The comparison of the model output using the previous and the current set of the biosphere model input parameters is presented in Section C.1. Section C.2 contains an evaluation of impact from the GoldSim version update. The combined effect of the input and the software change is not evaluated because the impact from the input parameter change is negligible (Section C.1) so the overall difference results almost entirely from the software change.

C1. EVALUATION OF INPUT CHANGE IMPACT ON THE MODELING RESULTS

The differences between the old and new input data are shown in Section 4.1, Table 4.1-5, describing direct inputs for this analysis. The differences in parameter values are very small and are limited to the values of cesium transfer factor for leafy vegetables, cesium transfer coefficient for eggs and the maximum value of mass loading for the volcanic indoor asleep environment. To evaluate the impact of these input changes the BDCFs, the biosphere model was executed for ^{137}Cs and ^{241}Am using the new set of input parameters (DTN: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150]) and the previously used version of software, i.e. GoldSim V7.50.100. ^{137}Cs was selected because the change in cesium transfer factor for leafy vegetables and cesium transfer coefficient for eggs only affects the BDCF components for ^{137}Cs. Americium-241 was selected because the maximum value of mass loading for the volcanic indoor asleep environment could only affect inhalation BDCF components, which are dominant components for the actinides, as shown in Table 6.2-7. Since the contributions of the inhalation BDCF components are very similar for all actinides (Table 6.2-7), the evaluation of the input change impact for only one of them was sufficient.

Table C.1-1 shows the statistics for the BDCFs for ^{137}Cs generated using the new input parameters and compares them to the BDCF statistics for this radionuclide generated using same software version with old inputs (DTN: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]). Table C.1-2 shows a similar comparison for ^{241}Am. The results of comparison are expressed in terms of percent relative difference between the BDCF statistics.

The relative differences between the BDCFs resulting from the input change are negligibly small, on the order of a fraction of a percent. It can be thus concluded that the BDCF differences due to the input value changes are insignificant.

Table C.1-1. Comparison of Biosphere Dose Conversion Factor Statistics for Cesium-137 for the Present-Day Climate Calculated Using GoldSim V7.50.100 and New Inputs with those Calculated Using Same Software and Old Inputs

Statistic	BDCF Components, New Inputs rem/yr per pCi/m^2			BDCF Components, Old Inputs rem/yr per pCi/m^2			Percent Relative Difference Between BDCF Components [a]		
	External, Ingestion and Radon	Short-term Inhalation	Long-term Inhalation	External, Ingestion and Radon	Short-term Inhalation	Long-term Inhalation	External, Ingestion and Radon	Short-term Inhalation	Long-term Inhalation
Mean	2.67E-08	6.78E-11	1.37E-10	2.67E-08	6.79E-11	1.37E-10	0.06	-0.07	0.00
STD	5.70E-10	4.11E-11	8.40E-11	5.53E-10	4.11E-11	8.40E-11	2.97	-0.02	0.00
Minimum	2.54E-08	6.32E-12	1.54E-11	2.54E-08	6.34E-12	1.54E-11	-0.02	-0.21	0.00
5%	2.59E-08	1.88E-11	4.45E-11	2.59E-08	1.88E-11	4.45E-11	0.00	-0.10	0.00
10%	2.61E-08	2.41E-11	5.57E-11	2.61E-08	2.42E-11	5.57E-11	0.06	-0.19	0.00
15%	2.62E-08	2.85E-11	6.35E-11	2.62E-08	2.86E-11	6.35E-11	0.02	-0.12	0.00
20%	2.63E-08	3.27E-11	7.18E-11	2.63E-08	3.27E-11	7.18E-11	0.02	-0.11	0.00
25%	2.64E-08	3.75E-11	7.87E-11	2.64E-08	3.75E-11	7.87E-11	0.03	-0.09	0.00
30%	2.65E-08	4.25E-11	8.47E-11	2.65E-08	4.25E-11	8.47E-11	-0.01	-0.08	0.00
35%	2.65E-08	4.71E-11	9.39E-11	2.65E-08	4.72E-11	9.39E-11	0.01	-0.14	0.00
40%	2.66E-08	5.08E-11	1.01E-10	2.66E-08	5.09E-11	1.01E-10	0.04	-0.11	0.00
45%	2.67E-08	5.54E-11	1.07E-10	2.66E-08	5.54E-11	1.07E-10	0.07	-0.11	0.00
50%	2.67E-08	5.98E-11	1.16E-10	2.67E-08	5.99E-11	1.16E-10	0.01	-0.10	0.00
55%	2.68E-08	6.51E-11	1.24E-10	2.68E-08	6.51E-11	1.24E-10	0.07	-0.03	0.00
60%	2.68E-08	7.09E-11	1.34E-10	2.68E-08	7.09E-11	1.34E-10	0.02	-0.02	0.00
65%	2.69E-08	7.58E-11	1.44E-10	2.69E-08	7.59E-11	1.44E-10	0.01	-0.07	0.00
70%	2.70E-08	8.10E-11	1.58E-10	2.70E-08	8.10E-11	1.58E-10	0.00	-0.02	0.00
75%	2.71E-08	8.67E-11	1.71E-10	2.70E-08	8.68E-11	1.71E-10	0.09	-0.04	0.00
80%	2.71E-08	9.74E-11	1.88E-10	2.71E-08	9.74E-11	1.88E-10	0.07	-0.03	0.00
85%	2.72E-08	1.07E-10	2.13E-10	2.72E-08	1.07E-10	2.13E-10	0.06	-0.06	0.00
90%	2.74E-08	1.15E-10	2.43E-10	2.73E-08	1.15E-10	2.43E-10	0.14	-0.12	0.00
95%	2.77E-08	1.44E-10	2.99E-10	2.76E-08	1.44E-10	2.99E-10	0.29	-0.04	0.00
Maximum	3.09E-08	2.67E-10	7.57E-10	3.08E-08	2.67E-10	7.57E-10	0.58	-0.01	0.00

[a] Calculated as (New BDCF – Old BDCF)/(Old BDCF)*100.

NOTE: STD=standard deviation, Min. = minimum, Max = maximum .

Table C.1-2. Comparison of Biosphere Dose Conversion Factor Statistics for Americium-241 for the Present-Day Climate Calculated Using GoldSim V7.50.100 and New Inputs with those Calculated Using Same Software and Old Inputs

Statistic	BDCF Components, New Inputs rem/yr per pCi/m^2			BDCF Components, Old Inputs rem/yr per pCi/m^2			Percent Relative Difference Between BDCF Components [a]		
	External, Ingestion and Radon	Short-term Inhalation	Long-term Inhalation	External, Ingestion and Radon	Short-term Inhalation	Long-term Inhalation	External, Ingestion and Radon	Short-term Inhalation	Long-term Inhalation
Mean	2.08E-09	9.43E-07	1.90E-06	2.08E-09	9.44E-07	1.90E-06	0.00	-0.07	0.00
STD	1.63E-09	5.71E-07	1.17E-06	1.63E-09	5.71E-07	1.17E-06	0.00	-0.02	0.00
Minimum	9.55E-10	8.79E-08	2.14E-07	9.55E-10	8.81E-08	2.14E-07	0.00	-0.21	0.00
5%	1.09E-09	2.61E-07	6.19E-07	1.09E-09	2.61E-07	6.19E-07	0.00	-0.09	0.00
10%	1.16E-09	3.35E-07	7.74E-07	1.16E-09	3.36E-07	7.74E-07	0.00	-0.20	0.00
15%	1.22E-09	3.97E-07	8.83E-07	1.22E-09	3.97E-07	8.83E-07	0.00	-0.13	0.00
20%	1.27E-09	4.55E-07	9.98E-07	1.27E-09	4.55E-07	9.98E-07	0.00	-0.11	0.00
25%	1.32E-09	5.21E-07	1.09E-06	1.32E-09	5.21E-07	1.09E-06	0.00	-0.09	0.00
30%	1.37E-09	5.91E-07	1.18E-06	1.37E-09	5.91E-07	1.18E-06	0.00	-0.08	0.00
35%	1.43E-09	6.55E-07	1.31E-06	1.43E-09	6.56E-07	1.31E-06	0.00	-0.14	0.00
40%	1.48E-09	7.07E-07	1.40E-06	1.48E-09	7.08E-07	1.40E-06	0.00	-0.11	0.00
45%	1.54E-09	7.70E-07	1.49E-06	1.54E-09	7.71E-07	1.49E-06	0.00	-0.11	0.00
50%	1.63E-09	8.32E-07	1.62E-06	1.63E-09	8.33E-07	1.62E-06	0.00	-0.09	0.00
55%	1.70E-09	9.05E-07	1.72E-06	1.70E-09	9.05E-07	1.72E-06	0.00	-0.03	0.00
60%	1.78E-09	9.86E-07	1.86E-06	1.78E-09	9.86E-07	1.86E-06	0.00	-0.02	0.00
65%	1.91E-09	1.05E-06	2.00E-06	1.91E-09	1.06E-06	2.00E-06	0.00	-0.07	0.00
70%	2.03E-09	1.13E-06	2.19E-06	2.03E-09	1.13E-06	2.19E-06	0.00	-0.02	0.00
75%	2.19E-09	1.21E-06	2.38E-06	2.19E-09	1.21E-06	2.38E-06	0.00	-0.04	0.00
80%	2.45E-09	1.35E-06	2.61E-06	2.45E-09	1.36E-06	2.61E-06	0.00	-0.03	0.00
85%	2.82E-09	1.49E-06	2.96E-06	2.82E-09	1.49E-06	2.96E-06	0.00	-0.07	0.00
90%	3.30E-09	1.60E-06	3.38E-06	3.30E-09	1.60E-06	3.38E-06	0.00	-0.13	0.00
95%	4.28E-09	2.00E-06	4.16E-06	4.28E-09	2.00E-06	4.16E-06	0.00	-0.04	0.00
Maximum	2.16E-08	3.72E-06	1.05E-05	2.16E-08	3.72E-06	1.05E-05	0.00	-0.01	0.00

[a] Calculated as (New BDCF – Old BDCF)/(Old BDCF)*100.
NOTE: STD=standard deviation, Min. = minimum, Max = maximum.

C2. EVALUATION OF SOFTWARE VERSION CHANGE IMPACT ON THE MODELING RESULTS

This section describes the assessment of the differences in the BDCF values resulting from the software change. The software used to calculate BDCFs in the previous revision of this analysis (BSC 2003 [DIRS 163958]) was GoldSim V7.50.100. This version was subsequently replaced with the GoldSim V8.01 SP4, which uses revised sampling algorithm for the Latin Hypercube sampling. Evaluation of the sampling algorithm effects on the biosphere model results was performed and is documented in this section. This evaluation corresponds to the Action 001 in CR-2222. The following steps were delineated in the action description:

1. Using GoldSim V8.01 SP4 or higher, rerun all biospheres analyses that rely on Latin Hypercube Sampling (LHS) for selecting parameter-input values.

2. Compare the outputs from these runs with outputs from earlier versions of GoldSim used in the analysis and model reports.

3. Determine the amount of variation between the two outputs for the mean, 95th percentile, and 5th percentile values.

4. If the variation is less than 10 percent document the results of the comparison and submit the documentation to the records package for the analysis and model reports.

5. If the variation is greater than 10 percent then submit the revised outputs to TSPA to evaluate the impact of the variation on the TSPA results.

6. Perform TSPA calculations with GoldSim V8.01 SP4 or higher using the revised inputs.

To evaluate the impact on the BDCFs, the biosphere model was executed using GoldSim V8.01 SP4 and the old set of input parameters (DTN: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]). Tables C.2-1 to C.2-3 show the statistics for the BDCF generated in such a manner for the three BDCF components. These statistics were compared to the statistics for the BDCFs generated using GoldSim V7.50.100 and the old input parameter values, which are shown in Tables C.2-4 to C.2-6). The results of comparison in terms of percent relative difference between the BDCF calculated using the two different version of GoldSim are presented in Tables C.2-7 to C.2-9 for the external/ingestion/radon, short-term inhalation, and long-term inhalation BDCF components, respectively.

The relative differences between the BDCFs resulting from the software change are relatively small. For the inhalation components, the differences between the BDCFs calculated using different version of GoldSim are almost the same for all radionuclides. For these components, the differences between the mean values are around 1 percent or less, and the differences for the

5th percentile and the 95th percentile values are less than 7 percent. For the external/ingestion/radon components, the differences between the BDCF calculated using different GoldSim versions depend on the radionuclide. Still, the mean values do not differ by more than 7 percent and the differences for the 5th percentile and the 95th percentile values exceed 10 percent for only one radionuclide, ^{237}Np, were the relative difference is less than 24 percent. The standard deviations, minimum and maximum values seem to be the most affected by the software change.

Because there was an instance when the variation between the results obtained using different GoldSim versions exceeded the 10 percent threshold for the statistics listed in step 3 of the Action 001 in CR-2222, step 5 was performed and new biosphere results were generated, as described in this report.

Table C.2-1. BDCF Component for External Exposure, Ingestion, and Inhalation of Radon Decay Products Calculated Using GoldSim V8.01 SP4 and the Old Inputs, rem/yr per pCi/m^2

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	2.11E-09	6.44E-10	9.38E-08	2.67E-08	7.12E-09	1.61E-07	2.38E-08	1.66E-08	2.30E-10	1.14E-07	6.91E-09	6.88E-08
STD	1.74E-09	2.04E-09	1.78E-09	5.96E-10	1.19E-08	1.01E-08	5.28E-09	1.50E-09	2.03E-10	2.90E-09	6.09E-09	2.02E-09
Min.	4.10E-10	1.73E-11	8.79E-08	2.52E-08	6.88E-10	1.41E-07	1.87E-08	1.48E-08	5.66E-11	1.07E-07	2.44E-09	6.46E-08
5%	6.45E-10	4.66E-11	9.12E-08	2.59E-08	1.39E-09	1.45E-07	1.97E-08	1.54E-08	7.76E-11	1.10E-07	2.93E-09	6.63E-08
10%	7.63E-10	6.44E-11	9.18E-08	2.61E-08	1.69E-09	1.48E-07	2.00E-08	1.55E-08	8.79E-11	1.11E-07	3.15E-09	6.68E-08
15%	8.66E-10	8.67E-11	9.22E-08	2.62E-08	1.91E-09	1.50E-07	2.03E-08	1.56E-08	9.75E-11	1.11E-07	3.34E-09	6.71E-08
20%	9.40E-10	1.05E-10	9.25E-08	2.63E-08	2.20E-09	1.52E-07	2.05E-08	1.57E-08	1.05E-10	1.12E-07	3.59E-09	6.73E-08
25%	1.03E-09	1.30E-10	9.27E-08	2.64E-08	2.46E-09	1.53E-07	2.08E-08	1.58E-08	1.15E-10	1.12E-07	3.78E-09	6.75E-08
30%	1.14E-09	1.49E-10	9.29E-08	2.65E-08	2.77E-09	1.55E-07	2.10E-08	1.59E-08	1.22E-10	1.12E-07	3.97E-09	6.77E-08
35%	1.22E-09	1.76E-10	9.32E-08	2.65E-08	3.04E-09	1.56E-07	2.12E-08	1.60E-08	1.31E-10	1.13E-07	4.21E-09	6.80E-08
40%	1.32E-09	2.10E-10	9.34E-08	2.66E-08	3.41E-09	1.58E-07	2.15E-08	1.60E-08	1.43E-10	1.13E-07	4.49E-09	6.82E-08
45%	1.44E-09	2.49E-10	9.36E-08	2.67E-08	3.95E-09	1.60E-07	2.18E-08	1.61E-08	1.53E-10	1.13E-07	4.74E-09	6.84E-08
50%	1.56E-09	2.96E-10	9.38E-08	2.67E-08	4.31E-09	1.61E-07	2.21E-08	1.62E-08	1.67E-10	1.13E-07	4.98E-09	6.85E-08
55%	1.69E-09	3.46E-10	9.40E-08	2.68E-08	4.77E-09	1.63E-07	2.25E-08	1.63E-08	1.81E-10	1.14E-07	5.34E-09	6.86E-08
60%	1.84E-09	4.10E-10	9.42E-08	2.68E-08	5.35E-09	1.64E-07	2.29E-08	1.64E-08	1.95E-10	1.14E-07	5.78E-09	6.88E-08
65%	2.04E-09	4.80E-10	9.44E-08	2.69E-08	5.93E-09	1.66E-07	2.33E-08	1.66E-08	2.13E-10	1.14E-07	6.25E-09	6.91E-08
70%	2.31E-09	5.56E-10	9.45E-08	2.70E-08	6.73E-09	1.68E-07	2.39E-08	1.67E-08	2.35E-10	1.15E-07	6.97E-09	6.93E-08
75%	2.58E-09	7.00E-10	9.48E-08	2.70E-08	7.80E-09	1.70E-07	2.45E-08	1.69E-08	2.58E-10	1.15E-07	7.72E-09	6.96E-08
80%	2.92E-09	8.56E-10	9.51E-08	2.71E-08	9.03E-09	1.71E-07	2.55E-08	1.72E-08	3.05E-10	1.15E-07	8.78E-09	6.99E-08
85%	3.42E-09	1.05E-09	9.53E-08	2.72E-08	1.07E-08	1.73E-07	2.70E-08	1.76E-08	3.61E-10	1.16E-07	1.01E-08	7.04E-08
90%	4.09E-09	1.33E-09	9.57E-08	2.73E-08	1.39E-08	1.75E-07	2.95E-08	1.83E-08	4.53E-10	1.17E-07	1.18E-08	7.08E-08
95%	5.39E-09	1.97E-09	9.63E-08	2.76E-08	1.91E-08	1.77E-07	3.28E-08	1.93E-08	5.85E-10	1.18E-07	1.72E-08	7.17E-08
Max.	2.11E-08	5.87E-08	1.18E-07	3.26E-08	2.40E-07	1.90E-07	7.83E-08	3.14E-08	2.24E-09	1.40E-07	7.17E-08	9.17E-08

Table C.2-1. BDCF Component for External Exposure, Ingestion, and Inhalation of Radon Decay Products Calculated Using GoldSim V8.01 SP4 and the Old Inputs, rem/yr per pCi/m^2 (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	3.54E-10	3.36E-10	3.11E-10	1.74E-09	2.11E-08	1.06E-09	1.17E-09	1.17E-09	1.11E-09	2.01E-09	1.15E-08
STD	3.46E-10	3.39E-10	3.22E-10	3.21E-10	2.20E-08	1.09E-09	1.20E-09	1.20E-09	1.14E-09	1.25E-09	1.25E-09
Min.	7.42E-11	6.03E-11	4.92E-11	1.45E-09	1.07E-08	1.58E-10	1.70E-10	1.72E-10	1.62E-10	9.53E-10	1.02E-08
5%	1.11E-10	9.72E-11	8.44E-11	1.51E-09	1.14E-08	2.71E-10	2.96E-10	2.97E-10	2.81E-10	1.10E-09	1.05E-08
10%	1.27E-10	1.13E-10	9.89E-11	1.53E-09	1.17E-08	3.27E-10	3.57E-10	3.59E-10	3.39E-10	1.16E-09	1.06E-08
15%	1.43E-10	1.28E-10	1.14E-10	1.54E-09	1.19E-08	3.68E-10	4.02E-10	4.04E-10	3.82E-10	1.21E-09	1.07E-08
20%	1.55E-10	1.40E-10	1.25E-10	1.55E-09	1.21E-08	4.17E-10	4.57E-10	4.59E-10	4.34E-10	1.26E-09	1.08E-08
25%	1.67E-10	1.51E-10	1.36E-10	1.57E-09	1.24E-08	4.64E-10	5.08E-10	5.10E-10	4.83E-10	1.32E-09	1.08E-08
30%	1.81E-10	1.66E-10	1.49E-10	1.58E-09	1.26E-08	5.10E-10	5.60E-10	5.61E-10	5.31E-10	1.37E-09	1.09E-08
35%	1.97E-10	1.81E-10	1.64E-10	1.59E-09	1.29E-08	5.52E-10	6.06E-10	6.08E-10	5.76E-10	1.42E-09	1.10E-08
40%	2.12E-10	1.96E-10	1.78E-10	1.61E-09	1.32E-08	6.07E-10	6.67E-10	6.68E-10	6.33E-10	1.48E-09	1.10E-08
45%	2.30E-10	2.14E-10	1.95E-10	1.62E-09	1.37E-08	6.56E-10	7.20E-10	7.22E-10	6.84E-10	1.55E-09	1.11E-08
50%	2.53E-10	2.36E-10	2.16E-10	1.64E-09	1.42E-08	7.21E-10	7.92E-10	7.94E-10	7.52E-10	1.62E-09	1.12E-08
55%	2.72E-10	2.55E-10	2.34E-10	1.67E-09	1.49E-08	7.99E-10	8.79E-10	8.80E-10	8.34E-10	1.71E-09	1.12E-08
60%	2.95E-10	2.78E-10	2.55E-10	1.69E-09	1.57E-08	8.57E-10	9.43E-10	9.44E-10	8.95E-10	1.79E-09	1.14E-08
65%	3.28E-10	3.10E-10	2.86E-10	1.72E-09	1.67E-08	9.64E-10	1.06E-09	1.06E-09	1.01E-09	1.92E-09	1.15E-08
70%	3.65E-10	3.46E-10	3.21E-10	1.75E-09	1.80E-08	1.08E-09	1.19E-09	1.19E-09	1.13E-09	2.04E-09	1.16E-08
75%	4.16E-10	3.95E-10	3.67E-10	1.79E-09	1.97E-08	1.21E-09	1.33E-09	1.33E-09	1.27E-09	2.20E-09	1.17E-08
80%	4.73E-10	4.52E-10	4.21E-10	1.85E-09	2.25E-08	1.44E-09	1.58E-09	1.58E-09	1.50E-09	2.44E-09	1.19E-08
85%	5.60E-10	5.37E-10	5.01E-10	1.94E-09	2.66E-08	1.70E-09	1.87E-09	1.87E-09	1.78E-09	2.79E-09	1.23E-08
90%	6.93E-10	6.68E-10	6.26E-10	2.04E-09	3.37E-08	2.23E-09	2.46E-09	2.46E-09	2.34E-09	3.34E-09	1.29E-08
95%	9.05E-10	8.76E-10	8.23E-10	2.24E-09	6.01E-08	2.89E-09	3.19E-09	3.19E-09	3.03E-09	4.12E-09	1.36E-08
Max.	5.02E-09	4.92E-09	4.65E-09	6.07E-09	4.06E-07	1.29E-08	1.42E-08	1.42E-08	1.35E-08	1.54E-08	2.49E-08

Source: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTES: Calculated in Excel file *Comparison of GoldSim versions_same inputs.xls* as shown in Appendix B.

STD = standard deviation, Min. = minimum, Max = maximum

Table C.2-2. BDCF Component for Short-Term Inhalation Exposure Calculated Using GoldSim V8.01 SP4 and the Old Inputs, rem/yr per pCi/m^2

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	5.32E-10	1.79E-11	2.17E-10	6.86E-11	4.98E-08	1.85E-08	1.44E-05	4.65E-06	6.99E-07	4.27E-06	2.76E-06	2.15E-06
STD	3.37E-10	1.13E-11	1.37E-10	4.34E-11	3.15E-08	1.17E-08	9.13E-06	2.94E-06	4.42E-07	2.70E-06	1.74E-06	1.36E-06
Min.	4.09E-11	1.37E-12	1.67E-11	5.27E-12	3.82E-09	1.42E-09	1.11E-06	3.57E-07	5.37E-08	3.28E-07	2.12E-07	1.66E-07
5%	1.43E-10	4.81E-12	5.85E-11	1.85E-11	1.34E-08	4.97E-09	3.89E-06	1.25E-06	1.88E-07	1.15E-06	7.42E-07	5.80E-07
10%	1.92E-10	6.45E-12	7.84E-11	2.47E-11	1.80E-08	6.66E-09	5.21E-06	1.68E-06	2.52E-07	1.54E-06	9.95E-07	7.78E-07
15%	2.31E-10	7.78E-12	9.45E-11	2.98E-11	2.16E-08	8.03E-09	6.28E-06	2.02E-06	3.04E-07	1.86E-06	1.20E-06	9.37E-07
20%	2.65E-10	8.92E-12	1.08E-10	3.42E-11	2.48E-08	9.21E-09	7.20E-06	2.32E-06	3.49E-07	2.13E-06	1.38E-06	1.07E-06
25%	2.95E-10	9.90E-12	1.20E-10	3.80E-11	2.75E-08	1.02E-08	7.99E-06	2.57E-06	3.87E-07	2.36E-06	1.53E-06	1.19E-06
30%	3.24E-10	1.09E-11	1.32E-10	4.18E-11	3.03E-08	1.12E-08	8.79E-06	2.83E-06	4.26E-07	2.60E-06	1.68E-06	1.31E-06
35%	3.52E-10	1.18E-11	1.44E-10	4.54E-11	3.30E-08	1.22E-08	9.56E-06	3.08E-06	4.63E-07	2.83E-06	1.83E-06	1.43E-06
40%	3.86E-10	1.30E-11	1.58E-10	4.98E-11	3.61E-08	1.34E-08	1.05E-05	3.37E-06	5.07E-07	3.10E-06	2.00E-06	1.56E-06
45%	4.22E-10	1.42E-11	1.72E-10	5.44E-11	3.95E-08	1.46E-08	1.14E-05	3.69E-06	5.54E-07	3.39E-06	2.19E-06	1.71E-06
50%	4.54E-10	1.52E-11	1.85E-10	5.85E-11	4.24E-08	1.57E-08	1.23E-05	3.96E-06	5.96E-07	3.64E-06	2.35E-06	1.84E-06
55%	4.85E-10	1.63E-11	1.98E-10	6.24E-11	4.53E-08	1.68E-08	1.31E-05	4.23E-06	6.37E-07	3.89E-06	2.51E-06	1.96E-06
60%	5.36E-10	1.80E-11	2.19E-10	6.90E-11	5.01E-08	1.86E-08	1.45E-05	4.68E-06	7.04E-07	4.30E-06	2.78E-06	2.17E-06
65%	5.77E-10	1.94E-11	2.36E-10	7.44E-11	5.40E-08	2.00E-08	1.57E-05	5.04E-06	7.58E-07	4.63E-06	2.99E-06	2.34E-06
70%	6.27E-10	2.11E-11	2.56E-10	8.07E-11	5.86E-08	2.17E-08	1.70E-05	5.47E-06	8.23E-07	5.03E-06	3.25E-06	2.54E-06
75%	6.89E-10	2.31E-11	2.81E-10	8.88E-11	6.44E-08	2.39E-08	1.87E-05	6.02E-06	9.05E-07	5.53E-06	3.57E-06	2.79E-06
80%	7.56E-10	2.54E-11	3.09E-10	9.75E-11	7.07E-08	2.62E-08	2.05E-05	6.61E-06	9.94E-07	6.07E-06	3.92E-06	3.06E-06
85%	8.38E-10	2.82E-11	3.42E-10	1.08E-10	7.84E-08	2.91E-08	2.27E-05	7.32E-06	1.10E-06	6.73E-06	4.34E-06	3.40E-06
90%	9.54E-10	3.21E-11	3.90E-10	1.23E-10	8.92E-08	3.31E-08	2.59E-05	8.34E-06	1.25E-06	7.66E-06	4.94E-06	3.86E-06
95%	1.20E-09	4.02E-11	4.88E-10	1.54E-10	1.12E-07	4.15E-08	3.24E-05	1.04E-05	1.57E-06	9.60E-06	6.20E-06	4.84E-06
Max.	2.39E-09	8.03E-11	9.76E-10	3.08E-10	2.23E-07	8.29E-08	6.48E-05	2.09E-05	3.14E-06	1.92E-05	1.24E-05	9.67E-06

Table C.2-2. BDCF Component for Short-Term Inhalation Exposure Calculated Using GoldSim V8.01 SP4 and the Old Inputs, rem/yr per pCi/m^2 (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	2.91E-07	2.84E-07	2.69E-07	2.54E-07	1.16E-06	8.42E-07	9.22E-07	9.22E-07	8.82E-07	9.53E-07	9.45E-07
STD	1.84E-07	1.80E-07	1.70E-07	1.61E-07	7.34E-07	5.33E-07	5.83E-07	5.83E-07	5.58E-07	6.03E-07	5.98E-07
Min.	2.24E-08	2.19E-08	2.07E-08	1.95E-08	8.92E-08	6.47E-08	7.08E-08	7.08E-08	6.78E-08	7.33E-08	7.27E-08
5%	7.83E-08	7.66E-08	7.25E-08	6.85E-08	3.12E-07	2.27E-07	2.48E-07	2.48E-07	2.37E-07	2.57E-07	2.55E-07
10%	1.05E-07	1.03E-07	9.72E-08	9.18E-08	4.19E-07	3.04E-07	3.33E-07	3.33E-07	3.18E-07	3.44E-07	3.41E-07
15%	1.26E-07	1.24E-07	1.17E-07	1.11E-07	5.05E-07	3.66E-07	4.01E-07	4.01E-07	3.84E-07	4.15E-07	4.11E-07
20%	1.45E-07	1.42E-07	1.34E-07	1.27E-07	5.79E-07	4.20E-07	4.60E-07	4.60E-07	4.40E-07	4.76E-07	4.72E-07
25%	1.61E-07	1.57E-07	1.49E-07	1.41E-07	6.42E-07	4.66E-07	5.10E-07	5.10E-07	4.88E-07	5.28E-07	5.23E-07
30%	1.77E-07	1.73E-07	1.64E-07	1.55E-07	7.07E-07	5.13E-07	5.61E-07	5.61E-07	5.37E-07	5.81E-07	5.76E-07
35%	1.93E-07	1.88E-07	1.78E-07	1.68E-07	7.68E-07	5.58E-07	6.10E-07	6.10E-07	5.84E-07	6.31E-07	6.26E-07
40%	2.11E-07	2.06E-07	1.95E-07	1.85E-07	8.42E-07	6.11E-07	6.69E-07	6.69E-07	6.40E-07	6.92E-07	6.86E-07
45%	2.31E-07	2.26E-07	2.14E-07	2.02E-07	9.20E-07	6.68E-07	7.31E-07	7.31E-07	6.99E-07	7.56E-07	7.50E-07
50%	2.48E-07	2.43E-07	2.30E-07	2.17E-07	9.89E-07	7.18E-07	7.86E-07	7.86E-07	7.52E-07	8.13E-07	8.06E-07
55%	2.65E-07	2.59E-07	2.45E-07	2.32E-07	1.06E-06	7.67E-07	8.39E-07	8.39E-07	8.03E-07	8.68E-07	8.61E-07
60%	2.93E-07	2.86E-07	2.71E-07	2.56E-07	1.17E-06	8.48E-07	9.28E-07	9.28E-07	8.88E-07	9.60E-07	9.52E-07
65%	3.15E-07	3.09E-07	2.92E-07	2.76E-07	1.26E-06	9.14E-07	1.00E-06	1.00E-06	9.57E-07	1.03E-06	1.03E-06
70%	3.42E-07	3.35E-07	3.17E-07	2.99E-07	1.37E-06	9.92E-07	1.09E-06	1.09E-06	1.04E-06	1.12E-06	1.11E-06
75%	3.76E-07	3.68E-07	3.49E-07	3.29E-07	1.50E-06	1.09E-06	1.19E-06	1.19E-06	1.14E-06	1.23E-06	1.22E-06
80%	4.13E-07	4.04E-07	3.83E-07	3.62E-07	1.65E-06	1.20E-06	1.31E-06	1.31E-06	1.25E-06	1.36E-06	1.34E-06
85%	4.58E-07	4.48E-07	4.24E-07	4.01E-07	1.83E-06	1.33E-06	1.45E-06	1.45E-06	1.39E-06	1.50E-06	1.49E-06
90%	5.21E-07	5.10E-07	4.83E-07	4.56E-07	2.08E-06	1.51E-06	1.65E-06	1.65E-06	1.58E-06	1.71E-06	1.70E-06
95%	6.54E-07	6.39E-07	6.05E-07	5.72E-07	2.61E-06	1.89E-06	2.07E-06	2.07E-06	1.98E-06	2.14E-06	2.13E-06
Max.	1.31E-06	1.28E-06	1.21E-06	1.14E-06	5.21E-06	3.78E-06	4.14E-06	4.14E-06	3.96E-06	4.28E-06	4.25E-06

Source: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814].

NOTES: Calculated in Excel file *Comparison of GoldSim versions_same inputs.xls* as shown in Appendix B. STD = standard deviation, Min. = minimum, Max = maximum.

Table C.2-3. BDCF Component for Long-Term Inhalation Exposure Calculated Using GoldSim V8.01 SP4 and the Old Inputs, rem/yr per pCi/m^2

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	1.06E-09	3.56E-11	4.33E-10	1.37E-10	9.92E-08	3.68E-08	2.88E-05	9.27E-06	1.39E-06	8.52E-06	5.50E-06	4.30E-06
STD	6.27E-10	2.11E-11	2.56E-10	8.08E-11	5.87E-08	2.18E-08	1.70E-05	5.48E-06	8.24E-07	5.03E-06	3.25E-06	2.54E-06
Min.	1.44E-10	4.82E-12	5.87E-11	1.85E-11	1.34E-08	4.98E-09	3.90E-06	1.25E-06	1.89E-07	1.15E-06	7.44E-07	5.82E-07
5%	3.37E-10	1.13E-11	1.38E-10	4.35E-11	3.15E-08	1.17E-08	9.15E-06	2.95E-06	4.43E-07	2.71E-06	1.75E-06	1.37E-06
10%	4.24E-10	1.42E-11	1.73E-10	5.46E-11	3.96E-08	1.47E-08	1.15E-05	3.70E-06	5.57E-07	3.40E-06	2.20E-06	1.72E-06
15%	4.77E-10	1.60E-11	1.95E-10	6.15E-11	4.46E-08	1.66E-08	1.29E-05	4.17E-06	6.27E-07	3.83E-06	2.47E-06	1.93E-06
20%	5.49E-10	1.85E-11	2.24E-10	7.08E-11	5.14E-08	1.91E-08	1.49E-05	4.80E-06	7.22E-07	4.41E-06	2.85E-06	2.22E-06
25%	6.05E-10	2.03E-11	2.47E-10	7.79E-11	5.65E-08	2.10E-08	1.64E-05	5.28E-06	7.95E-07	4.85E-06	3.13E-06	2.45E-06
30%	6.53E-10	2.19E-11	2.67E-10	8.41E-11	6.10E-08	2.26E-08	1.77E-05	5.70E-06	8.58E-07	5.24E-06	3.38E-06	2.64E-06
35%	6.99E-10	2.35E-11	2.86E-10	9.01E-11	6.54E-08	2.43E-08	1.90E-05	6.11E-06	9.19E-07	5.61E-06	3.62E-06	2.83E-06
40%	7.79E-10	2.62E-11	3.18E-10	1.00E-10	7.29E-08	2.70E-08	2.11E-05	6.81E-06	1.02E-06	6.25E-06	4.04E-06	3.15E-06
45%	8.39E-10	2.82E-11	3.43E-10	1.08E-10	7.85E-08	2.91E-08	2.28E-05	7.33E-06	1.10E-06	6.74E-06	4.35E-06	3.40E-06
50%	9.09E-10	3.05E-11	3.71E-10	1.17E-10	8.50E-08	3.15E-08	2.47E-05	7.94E-06	1.19E-06	7.30E-06	4.71E-06	3.68E-06
55%	9.99E-10	3.36E-11	4.08E-10	1.29E-10	9.34E-08	3.47E-08	2.71E-05	8.73E-06	1.31E-06	8.02E-06	5.18E-06	4.05E-06
60%	1.08E-09	3.64E-11	4.43E-10	1.40E-10	1.01E-07	3.76E-08	2.94E-05	9.47E-06	1.42E-06	8.70E-06	5.62E-06	4.39E-06
65%	1.18E-09	3.95E-11	4.80E-10	1.51E-10	1.10E-07	4.08E-08	3.19E-05	1.03E-05	1.54E-06	9.44E-06	6.09E-06	4.76E-06
70%	1.26E-09	4.24E-11	5.16E-10	1.63E-10	1.18E-07	4.38E-08	3.42E-05	1.10E-05	1.66E-06	1.01E-05	6.54E-06	5.11E-06
75%	1.37E-09	4.61E-11	5.61E-10	1.77E-10	1.28E-07	4.76E-08	3.72E-05	1.20E-05	1.80E-06	1.10E-05	7.11E-06	5.56E-06
80%	1.54E-09	5.16E-11	6.27E-10	1.98E-10	1.44E-07	5.33E-08	4.16E-05	1.34E-05	2.02E-06	1.23E-05	7.95E-06	6.22E-06
85%	1.66E-09	5.57E-11	6.78E-10	2.14E-10	1.55E-07	5.76E-08	4.50E-05	1.45E-05	2.18E-06	1.33E-05	8.60E-06	6.72E-06
90%	1.86E-09	6.24E-11	7.59E-10	2.39E-10	1.74E-07	6.45E-08	5.04E-05	1.62E-05	2.44E-06	1.49E-05	9.63E-06	7.53E-06
95%	2.26E-09	7.59E-11	9.23E-10	2.91E-10	2.11E-07	7.84E-08	6.13E-05	1.97E-05	2.97E-06	1.81E-05	1.17E-05	9.15E-06
Max.	4.92E-09	1.65E-10	2.01E-09	6.34E-10	4.60E-07	1.71E-07	1.34E-04	4.30E-05	6.47E-06	3.95E-05	2.55E-05	1.99E-05

Table C.2-3. BDCF Component for Long-Term Inhalation Exposure Calculated Using GoldSim V8.01 SP4 and the Old Inputs, rem/yr per pCi/m^2 (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	5.80E-07	5.67E-07	5.37E-07	5.07E-07	2.31E-06	1.68E-06	1.84E-06	1.84E-06	1.76E-06	1.90E-06	1.89E-06
STD	3.43E-07	3.35E-07	3.17E-07	3.00E-07	1.37E-06	9.93E-07	1.09E-06	1.09E-06	1.04E-06	1.12E-06	1.11E-06
Min.	7.85E-08	7.68E-08	7.27E-08	6.86E-08	3.13E-07	2.27E-07	2.49E-07	2.49E-07	2.38E-07	2.57E-07	2.55E-07
5%	1.84E-07	1.80E-07	1.71E-07	1.61E-07	7.35E-07	5.34E-07	5.84E-07	5.84E-07	5.59E-07	6.04E-07	5.99E-07
10%	2.32E-07	2.27E-07	2.15E-07	2.03E-07	9.24E-07	6.71E-07	7.34E-07	7.34E-07	7.03E-07	7.59E-07	7.53E-07
15%	2.61E-07	2.55E-07	2.42E-07	2.28E-07	1.04E-06	7.55E-07	8.27E-07	8.27E-07	7.91E-07	8.55E-07	8.48E-07
20%	3.00E-07	2.94E-07	2.78E-07	2.63E-07	1.20E-06	8.69E-07	9.51E-07	9.51E-07	9.10E-07	9.84E-07	9.76E-07
25%	3.30E-07	3.23E-07	3.06E-07	2.89E-07	1.32E-06	9.57E-07	1.05E-06	1.05E-06	1.00E-06	1.08E-06	1.07E-06
30%	3.57E-07	3.49E-07	3.30E-07	3.12E-07	1.42E-06	1.03E-06	1.13E-06	1.13E-06	1.08E-06	1.17E-06	1.16E-06
35%	3.82E-07	3.74E-07	3.54E-07	3.34E-07	1.52E-06	1.11E-06	1.21E-06	1.21E-06	1.16E-06	1.25E-06	1.24E-06
40%	4.26E-07	4.16E-07	3.94E-07	3.72E-07	1.70E-06	1.23E-06	1.35E-06	1.35E-06	1.29E-06	1.40E-06	1.38E-06
45%	4.59E-07	4.49E-07	4.25E-07	4.01E-07	1.83E-06	1.33E-06	1.45E-06	1.45E-06	1.39E-06	1.50E-06	1.49E-06
50%	4.97E-07	4.86E-07	4.60E-07	4.35E-07	1.98E-06	1.44E-06	1.57E-06	1.57E-06	1.51E-06	1.63E-06	1.62E-06
55%	5.46E-07	5.34E-07	5.06E-07	4.77E-07	2.18E-06	1.58E-06	1.73E-06	1.73E-06	1.66E-06	1.79E-06	1.77E-06
60%	5.92E-07	5.80E-07	5.49E-07	5.18E-07	2.36E-06	1.72E-06	1.88E-06	1.88E-06	1.80E-06	1.94E-06	1.93E-06
65%	6.43E-07	6.28E-07	5.95E-07	5.62E-07	2.56E-06	1.86E-06	2.04E-06	2.04E-06	1.95E-06	2.11E-06	2.09E-06
70%	6.90E-07	6.75E-07	6.39E-07	6.04E-07	2.75E-06	2.00E-06	2.19E-06	2.19E-06	2.09E-06	2.26E-06	2.24E-06
75%	7.50E-07	7.34E-07	6.95E-07	6.56E-07	2.99E-06	2.17E-06	2.38E-06	2.38E-06	2.28E-06	2.46E-06	2.44E-06
80%	8.39E-07	8.21E-07	7.77E-07	7.34E-07	3.35E-06	2.43E-06	2.66E-06	2.66E-06	2.54E-06	2.75E-06	2.73E-06
85%	9.07E-07	8.87E-07	8.40E-07	7.93E-07	3.62E-06	2.63E-06	2.87E-06	2.87E-06	2.75E-06	2.97E-06	2.95E-06
90%	1.02E-06	9.93E-07	9.41E-07	8.88E-07	4.05E-06	2.94E-06	3.22E-06	3.22E-06	3.08E-06	3.33E-06	3.30E-06
95%	1.24E-06	1.21E-06	1.14E-06	1.08E-06	4.93E-06	3.58E-06	3.91E-06	3.91E-06	3.75E-06	4.05E-06	4.02E-06
Max.	2.69E-06	2.63E-06	2.49E-06	2.35E-06	1.07E-05	7.79E-06	8.53E-06	8.53E-06	8.16E-06	8.82E-06	8.75E-06

Source: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814].

NOTES: Calculated in Excel file *Comparison of GoldSim versions_same inputs.xls* as shown in Appendix B.

STD = standard deviation, Min. = minimum, Max = maximum

Table C.2-4. BDCF Component for External Exposure, Ingestion, and Inhalation of Radon Decay Products Calculated Using GoldSim V7.50.100 and the Old Inputs, rem/yr per pCi/m^2

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	2.11E-09	6.03E-10	9.37E-08	2.67E-08	6.88E-09	1.61E-07	2.40E-08	1.67E-08	2.38E-10	1.14E-07	7.09E-09	6.88E-08
STD	1.68E-09	1.03E-09	1.58E-09	5.53E-10	1.03E-08	9.99E-09	6.84E-09	1.87E-09	2.54E-10	3.17E-09	6.98E-09	2.20E-09
Min.	4.17E-10	1.67E-11	8.95E-08	2.54E-08	7.18E-10	1.40E-07	1.85E-08	1.47E-08	5.63E-11	1.07E-07	2.50E-09	6.44E-08
5%	6.80E-10	4.71E-11	9.13E-08	2.59E-08	1.37E-09	1.46E-07	1.98E-08	1.54E-08	7.77E-11	1.10E-07	2.96E-09	6.63E-08
10%	7.78E-10	6.97E-11	9.17E-08	2.61E-08	1.70E-09	1.48E-07	2.01E-08	1.56E-08	8.97E-11	1.11E-07	3.17E-09	6.67E-08
15%	8.83E-10	8.77E-11	9.21E-08	2.62E-08	2.00E-09	1.50E-07	2.03E-08	1.56E-08	9.99E-11	1.11E-07	3.39E-09	6.71E-08
20%	9.63E-10	1.09E-10	9.24E-08	2.63E-08	2.26E-09	1.52E-07	2.06E-08	1.57E-08	1.06E-10	1.11E-07	3.57E-09	6.74E-08
25%	1.03E-09	1.30E-10	9.27E-08	2.64E-08	2.54E-09	1.53E-07	2.08E-08	1.58E-08	1.14E-10	1.12E-07	3.77E-09	6.76E-08
30%	1.11E-09	1.60E-10	9.29E-08	2.65E-08	2.76E-09	1.54E-07	2.10E-08	1.59E-08	1.22E-10	1.12E-07	3.95E-09	6.78E-08
35%	1.21E-09	1.93E-10	9.32E-08	2.65E-08	3.14E-09	1.56E-07	2.12E-08	1.59E-08	1.32E-10	1.13E-07	4.14E-09	6.80E-08
40%	1.33E-09	2.19E-10	9.34E-08	2.66E-08	3.49E-09	1.58E-07	2.14E-08	1.60E-08	1.40E-10	1.13E-07	4.41E-09	6.81E-08
45%	1.46E-09	2.44E-10	9.36E-08	2.66E-08	3.91E-09	1.60E-07	2.17E-08	1.61E-08	1.53E-10	1.13E-07	4.72E-09	6.83E-08
50%	1.60E-09	2.71E-10	9.38E-08	2.67E-08	4.31E-09	1.62E-07	2.21E-08	1.62E-08	1.65E-10	1.13E-07	5.08E-09	6.85E-08
55%	1.74E-09	3.17E-10	9.39E-08	2.68E-08	4.76E-09	1.63E-07	2.24E-08	1.63E-08	1.78E-10	1.14E-07	5.41E-09	6.87E-08
60%	1.87E-09	3.80E-10	9.42E-08	2.68E-08	5.32E-09	1.65E-07	2.29E-08	1.64E-08	1.94E-10	1.14E-07	5.82E-09	6.89E-08
65%	2.07E-09	4.58E-10	9.44E-08	2.69E-08	5.98E-09	1.66E-07	2.34E-08	1.65E-08	2.15E-10	1.14E-07	6.13E-09	6.91E-08
70%	2.30E-09	5.57E-10	9.46E-08	2.70E-08	6.89E-09	1.68E-07	2.40E-08	1.67E-08	2.34E-10	1.15E-07	6.91E-09	6.93E-08
75%	2.53E-09	6.81E-10	9.48E-08	2.70E-08	7.78E-09	1.70E-07	2.47E-08	1.69E-08	2.71E-10	1.15E-07	7.58E-09	6.95E-08
80%	2.85E-09	8.08E-10	9.51E-08	2.71E-08	8.96E-09	1.71E-07	2.59E-08	1.72E-08	3.05E-10	1.16E-07	8.59E-09	6.99E-08
85%	3.23E-09	1.07E-09	9.53E-08	2.72E-08	1.07E-08	1.73E-07	2.73E-08	1.76E-08	3.60E-10	1.16E-07	1.01E-08	7.03E-08
90%	3.98E-09	1.42E-09	9.56E-08	2.73E-08	1.36E-08	1.75E-07	2.96E-08	1.82E-08	4.33E-10	1.17E-07	1.25E-08	7.10E-08
95%	5.66E-09	2.19E-09	9.61E-08	2.76E-08	1.97E-08	1.77E-07	3.35E-08	1.94E-08	6.09E-10	1.19E-07	1.63E-08	7.21E-08
Max.	1.61E-08	1.83E-08	1.00E-07	3.08E-08	2.27E-07	1.84E-07	1.09E-07	3.78E-08	3.17E-09	1.42E-07	7.90E-08	1.03E-07

Table C.2-4. BDCF Component for External Exposure, Ingestion, and Inhalation of Radon Decay Products Calculated Using GoldSim V7.50.100 and the Old Inputs, rem/yr per pCi/m^2 (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	3.59E-10	3.40E-10	3.15E-10	1.74E-09	2.06E-08	1.12E-09	1.24E-09	1.24E-09	1.17E-09	2.08E-09	1.16E-08
STD	3.73E-10	3.66E-10	3.47E-10	3.46E-10	2.30E-08	1.43E-09	1.58E-09	1.58E-09	1.50E-09	1.63E-09	1.62E-09
Min.	6.58E-11	5.28E-11	4.24E-11	1.43E-09	1.08E-08	1.88E-10	2.02E-10	2.05E-10	1.93E-10	9.55E-10	1.01E-08
5%	1.07E-10	9.29E-11	8.03E-11	1.50E-09	1.15E-08	2.68E-10	2.91E-10	2.94E-10	2.77E-10	1.09E-09	1.06E-08
10%	1.22E-10	1.08E-10	9.44E-11	1.52E-09	1.17E-08	3.14E-10	3.43E-10	3.45E-10	3.26E-10	1.16E-09	1.07E-08
15%	1.40E-10	1.25E-10	1.11E-10	1.54E-09	1.19E-08	3.77E-10	4.12E-10	4.14E-10	3.91E-10	1.22E-09	1.07E-08
20%	1.54E-10	1.40E-10	1.25E-10	1.55E-09	1.21E-08	4.21E-10	4.61E-10	4.63E-10	4.37E-10	1.27E-09	1.08E-08
25%	1.68E-10	1.52E-10	1.36E-10	1.57E-09	1.24E-08	4.60E-10	5.04E-10	5.06E-10	4.78E-10	1.32E-09	1.09E-08
30%	1.83E-10	1.68E-10	1.51E-10	1.58E-09	1.28E-08	5.00E-10	5.49E-10	5.50E-10	5.21E-10	1.37E-09	1.09E-08
35%	1.98E-10	1.82E-10	1.65E-10	1.59E-09	1.32E-08	5.51E-10	6.05E-10	6.06E-10	5.74E-10	1.43E-09	1.10E-08
40%	2.17E-10	2.01E-10	1.83E-10	1.61E-09	1.35E-08	5.95E-10	6.53E-10	6.55E-10	6.20E-10	1.48E-09	1.10E-08
45%	2.36E-10	2.20E-10	2.01E-10	1.63E-09	1.39E-08	6.67E-10	7.33E-10	7.35E-10	6.96E-10	1.54E-09	1.11E-08
50%	2.53E-10	2.36E-10	2.16E-10	1.65E-09	1.44E-08	7.31E-10	8.04E-10	8.06E-10	7.63E-10	1.63E-09	1.11E-08
55%	2.79E-10	2.62E-10	2.40E-10	1.67E-09	1.50E-08	7.95E-10	8.75E-10	8.76E-10	8.30E-10	1.70E-09	1.12E-08
60%	3.10E-10	2.92E-10	2.69E-10	1.70E-09	1.59E-08	8.72E-10	9.60E-10	9.61E-10	9.11E-10	1.78E-09	1.13E-08
65%	3.37E-10	3.18E-10	2.94E-10	1.72E-09	1.65E-08	9.68E-10	1.07E-09	1.07E-09	1.01E-09	1.91E-09	1.15E-08
70%	3.83E-10	3.64E-10	3.37E-10	1.76E-09	1.75E-08	1.09E-09	1.20E-09	1.20E-09	1.14E-09	2.03E-09	1.16E-08
75%	4.24E-10	4.04E-10	3.75E-10	1.80E-09	1.96E-08	1.24E-09	1.36E-09	1.37E-09	1.30E-09	2.19E-09	1.17E-08
80%	4.88E-10	4.66E-10	4.34E-10	1.86E-09	2.17E-08	1.44E-09	1.58E-09	1.59E-09	1.50E-09	2.45E-09	1.19E-08
85%	5.76E-10	5.53E-10	5.17E-10	1.94E-09	2.53E-08	1.77E-09	1.95E-09	1.95E-09	1.85E-09	2.82E-09	1.24E-08
90%	6.69E-10	6.45E-10	6.03E-10	2.03E-09	3.16E-08	2.23E-09	2.46E-09	2.46E-09	2.34E-09	3.30E-09	1.29E-08
95%	9.24E-10	8.95E-10	8.40E-10	2.23E-09	4.87E-08	3.04E-09	3.36E-09	3.36E-09	3.19E-09	4.28E-09	1.38E-08
Max.	7.22E-09	7.07E-09	6.69E-09	8.09E-09	4.00E-07	1.86E-08	2.06E-08	2.06E-08	1.95E-08	2.16E-08	3.08E-08

Source: DTN: MO0307MWDDEBDC.001 [DIRS 164616].

NOTE: STD = standard deviation, Min. = minimum, Max = maximum

Table C.2-5. BDCF Component for Short-Term Inhalation Exposure Calculated Using GoldSim V7.50.100 and the Old Inputs, rem/yr per pCi/m^2

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	5.27E-10	1.77E-11	2.15E-10	6.79E-11	4.93E-08	1.83E-08	1.43E-05	4.60E-06	6.92E-07	4.23E-06	2.73E-06	2.13E-06
STD	3.19E-10	1.07E-11	1.30E-10	4.11E-11	2.98E-08	1.11E-08	8.65E-06	2.78E-06	4.19E-07	2.56E-06	1.65E-06	1.29E-06
Min.	4.92E-11	1.65E-12	2.01E-11	6.34E-12	4.60E-09	1.71E-09	1.33E-06	4.30E-07	6.46E-08	3.95E-07	2.55E-07	1.99E-07
5%	1.46E-10	4.90E-12	5.95E-11	1.88E-11	1.36E-08	5.06E-09	3.95E-06	1.27E-06	1.92E-07	1.17E-06	7.55E-07	5.90E-07
10%	1.87E-10	6.30E-12	7.66E-11	2.42E-11	1.75E-08	6.51E-09	5.08E-06	1.64E-06	2.46E-07	1.50E-06	9.71E-07	7.59E-07
15%	2.22E-10	7.45E-12	9.05E-11	2.86E-11	2.07E-08	7.69E-09	6.01E-06	1.94E-06	2.91E-07	1.78E-06	1.15E-06	8.97E-07
20%	2.54E-10	8.53E-12	1.04E-10	3.27E-11	2.38E-08	8.81E-09	6.89E-06	2.22E-06	3.34E-07	2.04E-06	1.32E-06	1.03E-06
25%	2.91E-10	9.77E-12	1.19E-10	3.75E-11	2.72E-08	1.01E-08	7.89E-06	2.54E-06	3.82E-07	2.34E-06	1.51E-06	1.18E-06
30%	3.30E-10	1.11E-11	1.35E-10	4.25E-11	3.09E-08	1.14E-08	8.95E-06	2.88E-06	4.34E-07	2.65E-06	1.71E-06	1.34E-06
35%	3.66E-10	1.23E-11	1.50E-10	4.72E-11	3.42E-08	1.27E-08	9.93E-06	3.20E-06	4.81E-07	2.94E-06	1.90E-06	1.48E-06
40%	3.95E-10	1.33E-11	1.61E-10	5.09E-11	3.69E-08	1.37E-08	1.07E-05	3.45E-06	5.19E-07	3.17E-06	2.05E-06	1.60E-06
45%	4.30E-10	1.44E-11	1.76E-10	5.54E-11	4.02E-08	1.49E-08	1.17E-05	3.76E-06	5.65E-07	3.45E-06	2.23E-06	1.74E-06
50%	4.65E-10	1.56E-11	1.90E-10	5.99E-11	4.35E-08	1.61E-08	1.26E-05	4.06E-06	6.11E-07	3.73E-06	2.41E-06	1.88E-06
55%	5.05E-10	1.70E-11	2.06E-10	6.51E-11	4.72E-08	1.75E-08	1.37E-05	4.41E-06	6.64E-07	4.05E-06	2.62E-06	2.05E-06
60%	5.50E-10	1.85E-11	2.25E-10	7.09E-11	5.15E-08	1.91E-08	1.49E-05	4.81E-06	7.23E-07	4.42E-06	2.85E-06	2.23E-06
65%	5.89E-10	1.98E-11	2.41E-10	7.59E-11	5.51E-08	2.04E-08	1.60E-05	5.15E-06	7.74E-07	4.73E-06	3.05E-06	2.39E-06
70%	6.29E-10	2.11E-11	2.57E-10	8.10E-11	5.88E-08	2.18E-08	1.71E-05	5.49E-06	8.26E-07	5.05E-06	3.26E-06	2.55E-06
75%	6.73E-10	2.26E-11	2.75E-10	8.68E-11	6.30E-08	2.34E-08	1.83E-05	5.88E-06	8.85E-07	5.40E-06	3.49E-06	2.73E-06
80%	7.56E-10	2.54E-11	3.09E-10	9.74E-11	7.07E-08	2.62E-08	2.05E-05	6.61E-06	9.94E-07	6.07E-06	3.92E-06	3.06E-06
85%	8.30E-10	2.79E-11	3.39E-10	1.07E-10	7.76E-08	2.88E-08	2.25E-05	7.25E-06	1.09E-06	6.66E-06	4.30E-06	3.36E-06
90%	8.95E-10	3.01E-11	3.66E-10	1.15E-10	8.37E-08	3.11E-08	2.43E-05	7.82E-06	1.18E-06	7.19E-06	4.64E-06	3.63E-06
95%	1.12E-09	3.76E-11	4.57E-10	1.44E-10	1.05E-07	3.88E-08	3.03E-05	9.77E-06	1.47E-06	8.98E-06	5.79E-06	4.53E-06
Max.	2.07E-09	6.97E-11	8.47E-10	2.67E-10	1.94E-07	7.20E-08	5.62E-05	1.81E-05	2.72E-06	1.66E-05	1.07E-05	8.40E-06

Table C.2-5. BDCF Component for Short-Term Inhalation Exposure Calculated Using GoldSim V7.50.100 and the Old Inputs, rem/yr per pCi/m^2 (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	2.88E-07	2.82E-07	2.67E-07	2.52E-07	1.15E-06	8.34E-07	9.12E-07	9.12E-07	8.73E-07	9.44E-07	9.36E-07
STD	1.74E-07	1.70E-07	1.61E-07	1.52E-07	6.95E-07	5.05E-07	5.52E-07	5.52E-07	5.28E-07	5.71E-07	5.66E-07
Min.	2.69E-08	2.63E-08	2.49E-08	2.35E-08	1.07E-07	7.78E-08	8.52E-08	8.52E-08	8.15E-08	8.81E-08	8.74E-08
5%	7.97E-08	7.79E-08	7.38E-08	6.97E-08	3.18E-07	2.31E-07	2.52E-07	2.52E-07	2.42E-07	2.61E-07	2.59E-07
10%	1.02E-07	1.00E-07	9.49E-08	8.96E-08	4.09E-07	2.97E-07	3.25E-07	3.25E-07	3.11E-07	3.36E-07	3.33E-07
15%	1.21E-07	1.18E-07	1.12E-07	1.06E-07	4.83E-07	3.51E-07	3.84E-07	3.84E-07	3.67E-07	3.97E-07	3.94E-07
20%	1.39E-07	1.36E-07	1.29E-07	1.21E-07	5.54E-07	4.02E-07	4.40E-07	4.40E-07	4.21E-07	4.55E-07	4.51E-07
25%	1.59E-07	1.56E-07	1.47E-07	1.39E-07	6.34E-07	4.60E-07	5.04E-07	5.04E-07	4.82E-07	5.21E-07	5.17E-07
30%	1.80E-07	1.76E-07	1.67E-07	1.58E-07	7.19E-07	5.22E-07	5.71E-07	5.71E-07	5.47E-07	5.91E-07	5.86E-07
35%	2.00E-07	1.96E-07	1.85E-07	1.75E-07	7.98E-07	5.80E-07	6.34E-07	6.34E-07	6.07E-07	6.56E-07	6.51E-07
40%	2.16E-07	2.11E-07	2.00E-07	1.89E-07	8.61E-07	6.25E-07	6.84E-07	6.84E-07	6.55E-07	7.08E-07	7.02E-07
45%	2.35E-07	2.30E-07	2.18E-07	2.06E-07	9.38E-07	6.81E-07	7.45E-07	7.45E-07	7.13E-07	7.71E-07	7.64E-07
50%	2.54E-07	2.48E-07	2.35E-07	2.22E-07	1.01E-06	7.36E-07	8.05E-07	8.05E-07	7.70E-07	8.33E-07	8.26E-07
55%	2.76E-07	2.70E-07	2.56E-07	2.41E-07	1.10E-06	8.00E-07	8.75E-07	8.75E-07	8.37E-07	9.05E-07	8.98E-07
60%	3.01E-07	2.94E-07	2.79E-07	2.63E-07	1.20E-06	8.71E-07	9.53E-07	9.53E-07	9.12E-07	9.86E-07	9.78E-07
65%	3.22E-07	3.15E-07	2.98E-07	2.82E-07	1.28E-06	9.32E-07	1.02E-06	1.02E-06	9.76E-07	1.06E-06	1.05E-06
70%	3.44E-07	3.36E-07	3.18E-07	3.00E-07	1.37E-06	9.95E-07	1.09E-06	1.09E-06	1.04E-06	1.13E-06	1.12E-06
75%	3.68E-07	3.60E-07	3.41E-07	3.22E-07	1.47E-06	1.07E-06	1.17E-06	1.17E-06	1.12E-06	1.21E-06	1.20E-06
80%	4.13E-07	4.04E-07	3.83E-07	3.61E-07	1.65E-06	1.20E-06	1.31E-06	1.31E-06	1.25E-06	1.36E-06	1.34E-06
85%	4.53E-07	4.43E-07	4.20E-07	3.96E-07	1.81E-06	1.31E-06	1.44E-06	1.44E-06	1.37E-06	1.49E-06	1.47E-06
90%	4.89E-07	4.79E-07	4.53E-07	4.28E-07	1.95E-06	1.42E-06	1.55E-06	1.55E-06	1.48E-06	1.60E-06	1.59E-06
95%	6.11E-07	5.98E-07	5.66E-07	5.35E-07	2.44E-06	1.77E-06	1.94E-06	1.94E-06	1.85E-06	2.00E-06	1.99E-06
Max.	1.13E-06	1.11E-06	1.05E-06	9.91E-07	4.52E-06	3.28E-06	3.59E-06	3.59E-06	3.44E-06	3.72E-06	3.68E-06

Source: DTN: MO0307MWDDEBDC.001 [DIRS 164616].

NOTE: STD = standard deviation, Min. = minimum, Max = maximum

Table C.2-6. BDCF Component for Long-Term Inhalation Exposure Calculated Using GoldSim V7.50.100 and the Old Inputs, rem/yr per pCi/m^2

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	1.06E-09	3.57E-11	4.33E-10	1.37E-10	9.93E-08	3.68E-08	2.88E-05	9.27E-06	1.39E-06	8.52E-06	5.50E-06	4.30E-06
STD	6.52E-10	2.19E-11	2.66E-10	8.40E-11	6.09E-08	2.26E-08	1.77E-05	5.69E-06	8.56E-07	5.23E-06	3.38E-06	2.64E-06
Min.	1.19E-10	4.01E-12	4.88E-11	1.54E-11	1.12E-08	4.14E-09	3.24E-06	1.04E-06	1.57E-07	9.58E-07	6.19E-07	4.83E-07
5%	3.46E-10	1.16E-11	1.41E-10	4.45E-11	3.23E-08	1.20E-08	9.37E-06	3.02E-06	4.54E-07	2.77E-06	1.79E-06	1.40E-06
10%	4.32E-10	1.45E-11	1.76E-10	5.57E-11	4.04E-08	1.50E-08	1.17E-05	3.77E-06	5.68E-07	3.47E-06	2.24E-06	1.75E-06
15%	4.93E-10	1.66E-11	2.01E-10	6.35E-11	4.61E-08	1.71E-08	1.34E-05	4.31E-06	6.48E-07	3.96E-06	2.55E-06	2.00E-06
20%	5.57E-10	1.87E-11	2.28E-10	7.18E-11	5.21E-08	1.93E-08	1.51E-05	4.87E-06	7.32E-07	4.47E-06	2.89E-06	2.26E-06
25%	6.11E-10	2.05E-11	2.49E-10	7.87E-11	5.71E-08	2.12E-08	1.66E-05	5.34E-06	8.03E-07	4.90E-06	3.16E-06	2.47E-06
30%	6.57E-10	2.21E-11	2.68E-10	8.47E-11	6.15E-08	2.28E-08	1.78E-05	5.74E-06	8.64E-07	5.28E-06	3.41E-06	2.66E-06
35%	7.29E-10	2.45E-11	2.98E-10	9.39E-11	6.82E-08	2.53E-08	1.98E-05	6.37E-06	9.58E-07	5.85E-06	3.78E-06	2.95E-06
40%	7.82E-10	2.63E-11	3.19E-10	1.01E-10	7.31E-08	2.71E-08	2.12E-05	6.83E-06	1.03E-06	6.28E-06	4.05E-06	3.17E-06
45%	8.34E-10	2.80E-11	3.41E-10	1.07E-10	7.80E-08	2.89E-08	2.26E-05	7.29E-06	1.10E-06	6.70E-06	4.32E-06	3.38E-06
50%	9.02E-10	3.03E-11	3.68E-10	1.16E-10	8.43E-08	3.13E-08	2.45E-05	7.88E-06	1.19E-06	7.24E-06	4.67E-06	3.65E-06
55%	9.60E-10	3.23E-11	3.92E-10	1.24E-10	8.98E-08	3.33E-08	2.60E-05	8.39E-06	1.26E-06	7.71E-06	4.98E-06	3.89E-06
60%	1.04E-09	3.49E-11	4.25E-10	1.34E-10	9.72E-08	3.61E-08	2.82E-05	9.08E-06	1.37E-06	8.35E-06	5.39E-06	4.21E-06
65%	1.12E-09	3.76E-11	4.57E-10	1.44E-10	1.05E-07	3.88E-08	3.03E-05	9.77E-06	1.47E-06	8.98E-06	5.79E-06	4.53E-06
70%	1.22E-09	4.11E-11	5.00E-10	1.58E-10	1.14E-07	4.25E-08	3.32E-05	1.07E-05	1.61E-06	9.83E-06	6.34E-06	4.96E-06
75%	1.33E-09	4.46E-11	5.42E-10	1.71E-10	1.24E-07	4.61E-08	3.60E-05	1.16E-05	1.74E-06	1.07E-05	6.88E-06	5.38E-06
80%	1.46E-09	4.90E-11	5.96E-10	1.88E-10	1.36E-07	5.06E-08	3.96E-05	1.27E-05	1.92E-06	1.17E-05	7.56E-06	5.91E-06
85%	1.65E-09	5.55E-11	6.75E-10	2.13E-10	1.54E-07	5.73E-08	4.48E-05	1.44E-05	2.17E-06	1.33E-05	8.56E-06	6.69E-06
90%	1.89E-09	6.34E-11	7.70E-10	2.43E-10	1.76E-07	6.55E-08	5.12E-05	1.65E-05	2.48E-06	1.51E-05	9.77E-06	7.64E-06
95%	2.32E-09	7.81E-11	9.49E-10	2.99E-10	2.17E-07	8.06E-08	6.30E-05	2.03E-05	3.05E-06	1.87E-05	1.20E-05	9.41E-06
Max.	5.88E-09	1.97E-10	2.40E-09	7.57E-10	5.50E-07	2.04E-07	1.59E-04	5.13E-05	7.72E-06	4.72E-05	3.05E-05	2.38E-05

Table C.2-6. BDCF Component for Long-Term Inhalation Exposure Calculated Using GoldSim V7.50.100 and the Old Inputs, rem/yr per pCi/m^2 (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	5.80E-07	5.67E-07	5.37E-07	5.07E-07	2.31E-06	1.68E-06	1.84E-06	1.84E-06	1.76E-06	1.90E-06	1.89E-06
STD	3.56E-07	3.48E-07	3.30E-07	3.11E-07	1.42E-06	1.03E-06	1.13E-06	1.13E-06	1.08E-06	1.17E-06	1.16E-06
Min.	6.52E-08	6.38E-08	6.04E-08	5.71E-08	2.60E-07	1.89E-07	2.07E-07	2.07E-07	1.98E-07	2.14E-07	2.12E-07
5%	1.89E-07	1.85E-07	1.75E-07	1.65E-07	7.53E-07	5.47E-07	5.99E-07	5.99E-07	5.73E-07	6.19E-07	6.14E-07
10%	2.36E-07	2.31E-07	2.19E-07	2.06E-07	9.42E-07	6.84E-07	7.48E-07	7.48E-07	7.16E-07	7.74E-07	7.68E-07
15%	2.69E-07	2.63E-07	2.49E-07	2.36E-07	1.07E-06	7.80E-07	8.54E-07	8.54E-07	8.17E-07	8.83E-07	8.76E-07
20%	3.04E-07	2.98E-07	2.82E-07	2.66E-07	1.21E-06	8.82E-07	9.65E-07	9.65E-07	9.23E-07	9.98E-07	9.90E-07
25%	3.34E-07	3.27E-07	3.09E-07	2.92E-07	1.33E-06	9.67E-07	1.06E-06	1.06E-06	1.01E-06	1.09E-06	1.09E-06
30%	3.59E-07	3.51E-07	3.33E-07	3.14E-07	1.43E-06	1.04E-06	1.14E-06	1.14E-06	1.09E-06	1.18E-06	1.17E-06
35%	3.98E-07	3.90E-07	3.69E-07	3.48E-07	1.59E-06	1.15E-06	1.26E-06	1.26E-06	1.21E-06	1.31E-06	1.29E-06
40%	4.27E-07	4.18E-07	3.96E-07	3.74E-07	1.71E-06	1.24E-06	1.35E-06	1.35E-06	1.30E-06	1.40E-06	1.39E-06
45%	4.56E-07	4.46E-07	4.22E-07	3.99E-07	1.82E-06	1.32E-06	1.44E-06	1.44E-06	1.38E-06	1.49E-06	1.48E-06
50%	4.93E-07	4.82E-07	4.57E-07	4.31E-07	1.97E-06	1.43E-06	1.56E-06	1.56E-06	1.49E-06	1.62E-06	1.60E-06
55%	5.25E-07	5.13E-07	4.86E-07	4.59E-07	2.09E-06	1.52E-06	1.66E-06	1.66E-06	1.59E-06	1.72E-06	1.71E-06
60%	5.68E-07	5.56E-07	5.26E-07	4.97E-07	2.27E-06	1.65E-06	1.80E-06	1.80E-06	1.72E-06	1.86E-06	1.85E-06
65%	6.11E-07	5.98E-07	5.66E-07	5.34E-07	2.44E-06	1.77E-06	1.94E-06	1.94E-06	1.85E-06	2.00E-06	1.99E-06
70%	6.69E-07	6.54E-07	6.20E-07	5.85E-07	2.67E-06	1.94E-06	2.12E-06	2.12E-06	2.03E-06	2.19E-06	2.18E-06
75%	7.26E-07	7.10E-07	6.72E-07	6.35E-07	2.89E-06	2.10E-06	2.30E-06	2.30E-06	2.20E-06	2.38E-06	2.36E-06
80%	7.97E-07	7.80E-07	7.39E-07	6.97E-07	3.18E-06	2.31E-06	2.53E-06	2.53E-06	2.42E-06	2.61E-06	2.59E-06
85%	9.03E-07	8.83E-07	8.36E-07	7.90E-07	3.60E-06	2.61E-06	2.86E-06	2.86E-06	2.74E-06	2.96E-06	2.94E-06
90%	1.03E-06	1.01E-06	9.55E-07	9.02E-07	4.11E-06	2.99E-06	3.27E-06	3.27E-06	3.13E-06	3.38E-06	3.35E-06
95%	1.27E-06	1.24E-06	1.18E-06	1.11E-06	5.07E-06	3.68E-06	4.02E-06	4.02E-06	3.85E-06	4.16E-06	4.13E-06
Max.	3.21E-06	3.14E-06	2.98E-06	2.81E-06	1.28E-05	9.30E-06	1.02E-05	1.02E-05	9.74E-06	1.05E-05	1.04E-05

Source: DTN: MO0307MWDDEBDC.001 [DIRS 164616].

NOTE: STD = standard deviation, Min. = minimum, Max = maximum

Table C.2-7. Comparison of BDCF Component for External Exposure, Ingestion, and Inhalation of Radon Decay Products Calculated Using GoldSim V8.01 SP 4 and GoldSim V7.50.100, Percent Relative Difference

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	-0.02	6.74	0.06	0.05	3.50	0.00	-1.15	-0.33	-3.18	-0.05	-2.57	-0.04
STD	3.03	98.75	12.76	7.72	15.71	0.63	-22.87	-19.94	-20.05	-8.74	-12.74	-8.14
Min.	-1.76	3.69	-1.88	-0.70	-4.25	0.85	1.31	0.78	0.41	-0.04	-2.38	0.29
5%	-5.13	-1.04	-0.08	-0.02	1.32	-0.12	-0.07	-0.52	-0.20	-0.10	-1.08	0.11
10%	-1.92	-7.52	0.04	0.03	-0.72	-0.07	-0.24	-0.40	-1.99	0.02	-0.40	0.01
15%	-1.90	-1.19	0.14	0.01	-4.51	0.16	-0.07	-0.02	-2.40	0.12	-1.64	0.05
20%	-2.41	-3.45	0.10	0.19	-2.48	0.25	-0.10	0.05	-1.17	0.16	0.58	-0.05
25%	0.59	0.10	0.07	0.11	-3.21	0.23	0.03	0.03	0.72	0.11	0.13	-0.11
30%	2.58	-6.79	0.07	0.00	0.37	0.15	0.19	0.10	0.15	0.07	0.54	-0.06
35%	0.29	-8.46	0.03	0.03	-3.21	-0.02	0.21	0.14	-0.68	0.06	1.75	0.02
40%	-0.94	-4.02	-0.01	0.08	-2.26	-0.14	0.25	0.29	2.50	0.04	1.67	0.05
45%	-0.88	2.04	0.04	0.06	1.05	-0.22	0.44	0.13	-0.08	0.05	0.32	0.09
50%	-2.58	9.17	0.03	-0.08	0.09	-0.30	0.24	0.12	1.05	-0.01	-1.98	-0.03
55%	-2.93	9.35	0.04	-0.06	0.12	-0.27	0.33	0.32	1.81	0.02	-1.33	-0.05
60%	-1.73	7.86	0.01	-0.09	0.52	-0.35	0.08	0.17	0.88	-0.08	-0.72	-0.08
65%	-1.78	4.74	-0.01	-0.10	-0.78	-0.25	-0.17	0.14	-1.20	-0.11	1.97	-0.01
70%	0.43	-0.31	-0.07	-0.03	-2.33	-0.16	-0.11	0.03	0.43	-0.09	0.84	0.01
75%	2.13	2.66	-0.05	-0.02	0.27	-0.05	-0.72	-0.13	-4.69	-0.10	1.73	0.11
80%	2.41	6.00	-0.03	-0.02	0.81	0.09	-1.32	0.19	-0.05	-0.10	2.13	0.01
85%	5.99	-2.16	0.03	0.07	-0.74	0.00	-1.39	0.25	0.13	-0.20	0.65	0.11
90%	2.66	-6.42	0.12	0.06	2.19	0.27	-0.21	0.38	4.67	-0.07	-5.37	-0.28
95%	-4.83	-9.86	0.19	0.12	-3.33	0.02	-2.16	-0.39	-3.93	-0.31	5.78	-0.57
Max.	30.89	220.70	17.62	5.88	5.71	3.14	-27.86	-16.81	-29.12	-1.03	-9.28	-10.92

Table C.2-7. Comparison of BDCF Component for External Exposure, Ingestion, and Inhalation of Radon Decay Products Calculated Using GoldSim V8.01 SP 4 and GoldSim V7.50.100, Percent Relative Difference (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	-1.31	-1.35	-1.38	-0.25	2.48	-5.25	-5.27	-5.26	-5.27	-3.01	-0.53
STD	-7.15	-7.15	-7.15	-7.19	-4.28	-24.15	-24.15	-24.15	-24.15	-23.16	-22.87
Min.	12.80	14.18	16.02	1.10	-0.92	-15.81	-15.87	-15.96	-16.09	-0.26	0.73
5%	4.14	4.65	5.13	0.12	-0.35	1.29	1.47	1.32	1.36	0.59	-0.53
10%	4.27	4.57	4.78	0.23	0.26	3.95	3.96	3.98	4.01	-0.52	-0.37
15%	2.10	2.28	2.43	0.25	0.15	-2.37	-2.43	-2.37	-2.37	-1.13	-0.20
20%	0.74	0.49	0.39	0.12	0.41	-0.82	-0.87	-0.82	-0.83	-0.51	-0.11
25%	-0.48	-0.58	-0.55	-0.01	-0.55	0.88	0.92	0.88	0.88	-0.47	-0.11
30%	-1.07	-1.24	-1.32	-0.08	-1.41	1.97	1.92	1.97	1.97	0.04	0.06
35%	-0.33	-0.45	-0.51	-0.15	-1.81	0.33	0.25	0.31	0.31	-0.58	-0.05
40%	-2.36	-2.40	-2.50	-0.14	-1.72	2.02	2.06	2.04	2.05	0.13	0.00
45%	-2.88	-2.90	-2.92	-0.52	-1.52	-1.74	-1.75	-1.75	-1.75	0.29	0.10
50%	0.04	-0.02	0.03	-0.43	-1.40	-1.43	-1.44	-1.43	-1.42	-0.67	0.29
55%	-2.39	-2.48	-2.57	-0.41	-0.37	0.47	0.44	0.47	0.46	0.81	0.26
60%	-4.81	-4.91	-5.02	-0.30	-0.86	-1.73	-1.80	-1.74	-1.76	0.46	0.47
65%	-2.59	-2.70	-2.82	-0.35	1.13	-0.41	-0.46	-0.41	-0.43	0.36	0.00
70%	-4.57	-4.77	-4.94	-0.64	2.86	-0.68	-0.68	-0.69	-0.69	0.72	-0.12
75%	-1.97	-2.07	-2.12	-0.50	0.57	-2.29	-2.30	-2.30	-2.30	0.52	-0.23
80%	-2.93	-3.02	-3.06	-1.02	3.74	-0.08	0.00	-0.06	-0.06	-0.59	-0.14
85%	-2.80	-2.93	-3.00	-0.37	5.44	-3.91	-3.97	-3.93	-3.94	-1.04	-0.34
90%	3.55	3.58	3.67	0.04	6.86	0.00	0.03	0.00	0.01	1.26	0.30
95%	-2.05	-2.08	-2.09	0.25	23.46	-4.92	-4.92	-4.93	-4.93	-3.79	-1.71
Max.	-30.39	-30.43	-30.47	-24.90	1.49	-30.89	-30.90	-30.90	-30.90	-28.60	-19.10

NOTES: Calculated in Excel file *Comparison of GoldSim versions_same inputs.xls* as shown in Appendix B.
STD = standard deviation, Min. = minimum, Max = maximum

Table C.2-8. Comparison of BDCF Component for Short-Term Inhalation Exposure Calculated Using GoldSim V8.01 SP 4 and GoldSim V7.50.100, Percent Relative Difference

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
STD	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54
Min.	-16.84	-16.84	-16.84	-16.84	-16.84	-16.84	-16.85	-16.84	-16.84	-16.85	-16.84	-16.85
5%	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70
10%	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43
15%	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43
20%	4.50	4.50	4.49	4.50	4.49	4.50	4.50	4.49	4.49	4.50	4.49	4.50
25%	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23
30%	-1.74	-1.74	-1.74	-1.74	-1.74	-1.75	-1.74	-1.74	-1.74	-1.74	-1.74	-1.74
35%	-3.76	-3.77	-3.76	-3.76	-3.76	-3.76	-3.76	-3.76	-3.76	-3.77	-3.76	-3.76
40%	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23
45%	-1.88	-1.89	-1.88	-1.88	-1.88	-1.89	-1.88	-1.88	-1.88	-1.88	-1.89	-1.88
50%	-2.35	-2.34	-2.34	-2.35	-2.35	-2.35	-2.35	-2.35	-2.35	-2.35	-2.35	-2.34
55%	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10
60%	-2.64	-2.64	-2.64	-2.64	-2.64	-2.64	-2.64	-2.64	-2.64	-2.64	-2.64	-2.64
65%	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
70%	-0.34	-0.34	-0.35	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34
75%	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32
80%	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
85%	1.07	1.07	1.07	1.07	1.07	1.07	1.06	1.07	1.07	1.07	1.07	1.07
90%	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58
95%	6.95	6.94	6.94	6.94	6.94	6.95	6.94	6.95	6.95	6.95	6.94	6.95
Max.	15.20	15.20	15.20	15.20	15.21	15.20	15.20	15.21	15.20	15.20	15.21	15.20

Table C.2-8. Comparison of BDCF Component for Short-Term Inhalation Exposure Calculated Using GoldSim V8.01 SP 4 and GoldSim V7.50.100, Percent Relative Difference (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
STD	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54
Min.	-16.84	-16.84	-16.84	-16.84	-16.84	-16.84	-16.84	-16.84	-16.84	-16.84	-16.84
5%	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70	-1.70
10%	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43
15%	4.43	4.44	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43
20%	4.49	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
25%	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23
30%	-1.74	-1.74	-1.74	-1.74	-1.74	-1.74	-1.74	-1.74	-1.74	-1.74	-1.74
35%	-3.76	-3.76	-3.77	-3.77	-3.76	-3.76	-3.76	-3.76	-3.76	-3.76	-3.76
40%	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23	-2.23
45%	-1.89	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88
50%	-2.35	-2.34	-2.35	-2.35	-2.35	-2.35	-2.35	-2.35	-2.35	-2.35	-2.35
55%	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10	-4.10
60%	-2.64	-2.64	-2.64	-2.64	-2.63	-2.64	-2.64	-2.64	-2.64	-2.64	-2.64
65%	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-1.99
70%	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.34	-0.35	-0.34	-0.35
75%	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.33	2.32	2.32
80%	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
85%	1.07	1.07	1.07	1.07	1.06	1.07	1.07	1.07	1.07	1.07	1.07
90%	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58	6.58
95%	6.94	6.94	6.95	6.95	6.94	6.95	6.94	6.94	6.94	6.94	6.95
Max.	15.20	15.20	15.20	15.21	15.20	15.21	15.20	15.20	15.20	15.21	15.20

NOTES: Calculated in Excel file *Comparison of GoldSim versions_same inputs.xls* as shown in Appendix B.
STD = standard deviation, Min. = minimum, Max = maximum

Table C.2-9. Comparison of BDCF Component for Long-Term Inhalation Exposure Calculated Using GoldSim V8.01 SP 4 and GoldSim V7.50.100, Percent Relative Difference

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
STD	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75
Min.	20.30	20.30	20.30	20.30	20.31	20.30	20.30	20.30	20.30	20.30	20.30	20.30
5%	-2.43	-2.42	-2.43	-2.43	-2.43	-2.43	-2.43	-2.43	-2.43	-2.43	-2.43	-2.43
10%	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88
15%	-3.16	-3.15	-3.16	-3.16	-3.16	-3.16	-3.16	-3.16	-3.16	-3.16	-3.16	-3.16
20%	-1.40	-1.40	-1.40	-1.40	-1.40	-1.40	-1.40	-1.40	-1.40	-1.40	-1.40	-1.40
25%	-1.01	-1.01	-1.01	-1.01	-1.01	-1.01	-1.01	-1.01	-1.01	-1.01	-1.01	-1.01
30%	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70
35%	-4.04	-4.04	-4.04	-4.03	-4.03	-4.04	-4.03	-4.04	-4.03	-4.04	-4.04	-4.04
40%	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39
45%	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
50%	0.79	0.80	0.79	0.79	0.79	0.79	0.80	0.79	0.79	0.79	0.79	0.79
55%	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02
60%	4.26	4.26	4.26	4.26	4.26	4.26	4.26	4.26	4.26	4.26	4.26	4.26
65%	5.14	5.14	5.13	5.13	5.14	5.13	5.13	5.13	5.14	5.13	5.14	5.13
70%	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15
75%	3.39	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40
80%	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20
85%	0.44	0.44	0.44	0.44	0.44	0.45	0.45	0.44	0.45	0.45	0.44	0.45
90%	-1.48	-1.47	-1.48	-1.47	-1.48	-1.47	-1.48	-1.47	-1.48	-1.48	-1.47	-1.47
95%	-2.73	-2.73	-2.73	-2.73	-2.73	-2.73	-2.73	-2.73	-2.73	-2.73	-2.73	-2.73
Max.	-16.24	-16.24	-16.24	-16.24	-16.25	-16.24	-16.24	-16.25	-16.24	-16.24	-16.24	-16.25

Table C.2-9. Comparison of BDCF Component for Long-Term Inhalation Exposure Calculated Using GoldSim V8.01 SP 4 and GoldSim V7.50.100, Percent Relative Difference (Continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
STD	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75	-3.75
Min.	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30
5%	-2.43	-2.43	-2.43	-2.42	-2.43	-2.43	-2.43	-2.43	-2.43	-2.43	-2.43
10%	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88	-1.88
15%	-3.16	-3.16	-3.15	-3.16	-3.16	-3.16	-3.16	-3.16	-3.16	-3.16	-3.16
20%	-1.40	-1.40	-1.40	-1.41	-1.40	-1.40	-1.40	-1.40	-1.40	-1.40	-1.40
25%	-1.01	-1.01	-1.01	-1.01	-1.01	-1.01	-1.00	-1.00	-1.01	-1.01	-1.01
30%	-0.70	-0.69	-0.69	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70
35%	-4.03	-4.04	-4.03	-4.04	-4.03	-4.04	-4.04	-4.04	-4.04	-4.03	-4.04
40%	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39	-0.39
45%	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
50%	0.79	0.79	0.80	0.79	0.79	0.80	0.79	0.79	0.79	0.80	0.79
55%	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02
60%	4.26	4.26	4.26	4.26	4.26	4.26	4.26	4.26	4.26	4.26	4.26
65%	5.13	5.13	5.14	5.14	5.14	5.13	5.13	5.13	5.13	5.14	5.14
70%	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15
75%	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40
80%	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20
85%	0.45	0.44	0.45	0.44	0.45	0.44	0.44	0.44	0.44	0.44	0.45
90%	-1.48	-1.48	-1.48	-1.48	-1.47	-1.47	-1.48	-1.48	-1.48	-1.47	-1.47
95%	-2.73	-2.73	-2.73	-2.72	-2.73	-2.73	-2.73	-2.73	-2.73	-2.73	-2.73
Max.	-16.24	-16.24	-16.24	-16.25	-16.24	-16.24	-16.24	-16.24	-16.24	-16.24	-16.25

NOTES: Calculated in Excel file *Comparison of GoldSim versions_same inputs.xls* as shown in Appendix B.
STD = standard deviation, Min. = minimum, Max = maximum

C3. EVALUATION OF INPUT AND SOFTWARE VERSION CHANGE IMPACT ON THE MODELING RESULTS

This section describes the evaluation of the combined differences in the BDCF values resulting from the input and software change. In doing so, the new BDCFs developed in this analysis are compared to the BDCFs developed in the previous revision of the analysis and the differences are evaluated.

The differences resulting from the input changes are described in Section C.1; the differences resulting from the software changes are described in Section C.2. As stated in Section C.1, the relative differences between the BDCFs resulting from the input change are negligibly small, on the order of a fraction of a percent, and the input changes concern only one element, cesium, and one pathway, short-term inhalation, for all radionuclides. It can be thus concluded that the BDCF differences are only due to the software changes.

Tables C.2-7 to C.2-9 show that the differences between the values of BDCF components are small. For most radionuclides, inhalation of particular matter is a dominant exposure pathway (Table 6.2-7). The mean values of the inhalation components for all radionuclides differ by just 0.03 percent for the long-term inhalation component (a more important component in the calculations of the expected dose from a volcanic eruption) and by 1.04 percent for the short-term inhalation component. The differences in the statistics between 5th and 95th percentile are less than a few percent. Only the far tails of the distributions are affected, with the differences up to about 20 percent.

For the external exposure, ingestion, and radon BDCF component, the differences in the mean values are radionuclide-dependent and are less than 7 percent. The differences in the percentiles of the distribution between 5th and 95th percentile are less than ten percent for all radionuclides except ^{237}Np. However, for this radionuclide, the inhalation pathway is dominant and the contribution of the external exposure and ingestion to the all-pathway dose is negligible.

It can thus be concluded that the differences between the BDCFs calculated in the previous revision of this analysis and the new BDCFs developed in this analysis are equivalent and can be used interchangeably.

APPENDIX D

DATA QUALIFICATION PLAN

BSC	Data Qualification Plan	QA: QA Page 1 of 1

Section I. Organizational Information

Qualification Title

Disruptive Event Biosphere Dose Conversion Factors

Requesting Organization

Regulatory Integration Team/Natural Systems/Biosphere

Section II. Process Planning Requirements

1. List of Unqualified Data to be Evaluated

DTN: MO0307MWDDEBDC.001, Disruptive Event Biosphere Dose Conversion Factors. This data set includes the results of *Disruptive Event Biosphere Dose Conversion Factor Analysis*, ANL-MGR-MD-000003 Rev 02 - it is a product output of this analysis. The DTN has been downgraded to unqualified due to the source data problems.

2. Type of Data Qualification Method(s) [Including rationale for selection of method(s) (Attachment 3) and qualification attributes (Attachment 4)]

The data will be qualified according to the corroborating data qualification method identified in AP-SIII.2Q, REV 1/ICN 2, or current version). This method was chosen to establish the confidence in the appropriateness of the data and to demonstrate that it is suitable for the intended use as input to the TSPA model. The attributes considered will be: (1) qualification of personnel or organizations generating the data (2) a corroborative comparison with the data developed under the OCRWM QA program to confirm that the data used are reasonable.

3. Data Qualification Team and Additional Support Staff Required

Maryla Wasiolek, Chairperson and Technical Representative. Maryla Wasiolek is a senior scientist with Bechtel SAIC Co., LLC (BSC) Regulatory Integration Team/Natural Systems/Biosphere. She has a M.Sc and Ph.D in applied nuclear physics/nuclear engineering.. Dr. Wasiolek has been involved in radiological assessment and radioecology for over 20 years. She has 7 years of experience on the Yucca Mountain Project.

Ernesto Faillace, Radiological Engineer. Ernesto Faillace is a certified health physicist with RCS Corporation and a member of the Regulatory Integration Team/Natural Systems/Biosphere. He has B.S. and M.S. degrees in nuclear engineering and a doctor of engineering degree with a health physics specialty. Dr. Faillace has 15 years of experience in radiological assessments, of which seven have been with the RESRAD pathways analysis model.

4. Data Evaluation Criteria

The data will be considered qualified for use as input to the TSPA model if the difference between the mean, 5th percentile and the 95th percentile of the BDCFs included in the data set being qualified and the BDCF data developed in *Disruptive Event Biosphere Dose Conversion Factor Analysis*, ANL-MGR-MD-000003 Rev 03 are not greater than 10 percent. This data evaluation criterion is consistent with the criterion established to evaluate an impact of software change from GoldSim 7.50.100 to GoldSim 8.01 SP4, as given in the condition report CR-2222, which is a primary reason for differences in the BDCF data. If the difference between the statistics is greater than 10 percent, the data may still be appropriate for the intended use, however the demonstration of applicability will need to be made by the TSPA staff. This will be noted in the discussion of limits or caveats that should be considered by potential users of the data.

5. Identification of Procedures Used

The primary procedure used to control the data qualification process will be AP-SIII.2Q, Qualification of Unqualified Data. The documentationof the qualification process and findings will be done in accordance with AP-SIII.9Q, Scientific Analyses. Other procedures will be followed as required by AP-SIII.9Q.

Section III. Approval

Qualification Chairperson Printed Name	Qualification Chairperson Signature	Date
Maryla Wasiolek	Maryla Wasiolek	7/21/2004
Responsible Manager Printed Name	**Responsible Manager Signature**	**Date**
Ming Zhu	Ahmed M Monib for Ming Zhu	7/21/04

AP-SIII.2Q PA_ASIII2-1 (Rev. 01/29/2004)

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APPENDIX E

VERIFICATION OF ERMYN MODEL FILES FOR GOLDSIM VERSION 8.01 SP4

The ERMYN model for the volcanic ash exposure scenario (DTN: MO0306MWDBGSMF.001 [DIRS 163816]) was constructed and verified for GoldSim V7.50.100. Verification was conducted for two radionuclides: ^{226}Ra, and ^{239}Pu because these two radionuclides are representative of all environmental transport and exposure pathways included in the model for the volcanic ash exposure scenario. To verify the applicability of GoldSim V8.01 SP4 as software supporting the biosphere model, the original model verification files were opened in GoldSim V8.01 SP4 and the verification calculations were repeated.

Figure E-1 shows the list of the original verification files as well as the model files generated in this analysis when the original files were run using GoldSim V8.01 SP4. Table E-1 shows the results from the original verification files and their re-runs in GoldSim V8.01 SP4. The results are identical, so the model can be executed using GoldSim V8.01 SP4.

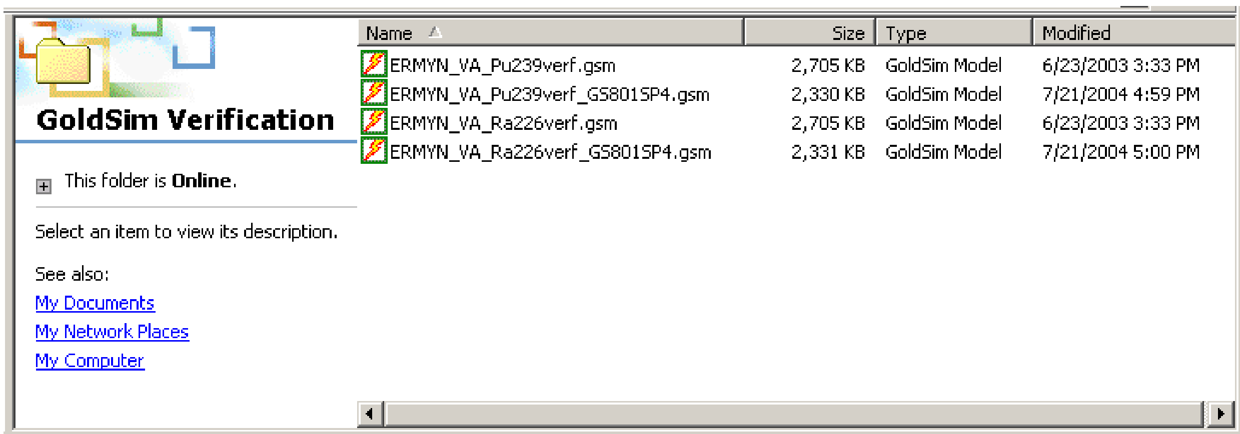

Figure E-1. Model Verification Files Obtained Using GoldSim Versions 7.50.100 and 8.01 SP4

Table E-1. Results of Verification Runs Using GoldSim Versions 7.50.100 and 8.01 SP4

Radionuclide	Pathway	BDCF (rem/yr per pCi/L)	
		GoldSim V7.50.100	GoldSim V8.01 SP4
Pu-239	External	1.392100E-11	1.392100E-11
	Inhalation Short	6.899400E-07	6.899400E-07
	Inhalation Long	1.304500E-06	1.304500E-06
	Radon	0.000000E+00	0.000000E+00
	Leafy vegetables	1.683300E-11	1.683300E-11
	Other vegetabels	3.668600E-12	3.668600E-12
	Fruit	1.558700E-11	1.558700E-11
	Grain	1.222700E-12	1.222700E-12
	Meat	2.678200E-13	2.678200E-13
	Milk	1.045500E-14	1.045500E-14
	Poultry	9.577700E-14	9.577700E-14
	Eggs	1.712200E-12	1.712200E-12
	Soil Ingestion	3.445200E-10	3.445200E-10
	File name	ERMYN_VA_Pu239verf.gsm	ERMYN_VA_Pu239verf_GS801SP4.gsm
Ra-226	External	7.848800E-08	7.848800E-08
	Inhalation Short	1.382200E-08	1.382200E-08
	Inhalation Long	2.613400E-08	2.613400E-08
	Radon	8.033000E-08	8.033000E-08
	Leafy vegetabels	6.963500E-11	6.963500E-11
	Other vegetabes	2.171200E-11	2.171200E-11
	Fruit	4.413500E-11	4.413500E-11
	Grain	2.720000E-12	2.720000E-12
	Meat	1.330500E-11	1.330500E-11
	Milk	2.035000E-11	2.035000E-11
	Poultry	5.267100E-13	5.267100E-13
	Eggs	1.524800E-13	1.524800E-13
	Soil Ingestion	1.291000E-10	1.291000E-10
	File name	ERMYN_VA_Ra226verf.gsm	ERMYN_VA_Ra226verf_GS801SP4.gsm

Files without a GoldSim version number (*_GS801SP4) in their title apply to V7.50.100.

NOTE: veg. = vegetables